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THE EFFECTIVE DRAG FUNCTIONS FOR DIGITAL GUNFIRE CONTROL SYSTEMS

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FOREWORD

The functionalization of projectile ballistics data described herein was conducted by the Naval Weapons Laboratory during Fiscal Years 1971 and 1972. This work was sponsored jointly by Independent Exploratory Development Funds and by the Naval Ordnance Systems Command.

This report was reviewed by R. D. Cuddy, Head, Aeroballistics Division.

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ABSTRACT

The Effective Drag Functions derived by the Naval Weapons Laboratory for the computation of gun ballistic data in digital gunfire control systems are presented. The accuracy and derivation of the functions are given as well as the least-squares coefficients computed for 3- and 5-inch projectiles. FORTRAN listings of the three programs used in the computation of the coefficients are given in the appendices.

CONTENTS

I. INTRODUCTION

Reference 1 states: "A gun weapon system is functionally composed of the following elements: (1) a fire control system, (2) one or more gun mounts organized as a battery, and (3) ammunition supply arrangements. With guns, fire control can be considered as the practical application of exterior ballistics to ensure that the projectile will hit the target. In any weapon system, the fire control problem is essentially that of getting the weapon or projectile to hit the target and explode, or at least to explode when the target and the weapon or projectile approach close enough for maximum damaging effect. In gun weapon systems, the problem is to *lay* (aim) the gun in such a way that the projectile will hit or approach close to the target. Unlike other types of weapon systems, once the projectile has left the gun muzzle, nothing further can be done to affect its course. The gun's fire control problem ideally must be solved before the gun fires. To solve the gun fire control problem, it is necessary to deal with three main types of variables: (1) exterior ballistics, (2) target position and relative motion of target and own ship, and (3) inherent corrections necessitated by the physical characteristics of the weapon system and the medium on which its carrier floats."

As indicated above, one of the major roles of the fire control system is to accurately predict the exterior ballistic performance of the projectile since nothing can be done to affect its course once it has exited the muzzle. Ultimately then, the accuracy with which the system can predict the projectile's trajectory provides an upper limit on the capability of the system to achieve its designed purpose, i.e., incur maximum damaging effect on the target. From the instant the projectile leaves the muzzle of the gun until it ends its flight by impact or explosion, the projectile trajectory is affected by the following factors: (1) momentum, (2) gravity, (3) air resistance, (4) wind, (5) drift, (6) earth's rotation (Coriolis), and (7) earth's curvature. Thus, the fire control system must make provision for these factors in aiming the gun such that the projectile will intersect the path of the target.

Normally, a range table[1] (i.e., firing table) is constructed for each projectile based on exterior ballistics theory and information gained from the analysis of instrumented flight tests of the projectile. The range table is based on a set of nominal or standard firing conditions for the weapon and provides differential effects for variables such as initial velocity, projectile weight, air density, air temperature, wind, and gun and target motion. The table gives elevation angle, time-of-flight, and drift for standard firing conditions; using the differential effects, corrections can be applied to the data for standard firing conditions to obtain a gun elevation angle

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[1]See Reference 2, 3, and 4.

and an azimuth angle for any combination of firing conditions that may exist. It should be noted that the range table is an approximation to the trajectory of the projectile. Solutions for non-standard firing conditions have inherent errors in them due to the non-linearity of the differential effects given in the table and the interaction of multiple effects operating simultaneously.[2]

Reference 1 defines ***fire control computers*** or ***rangekeepers*** as electronic or electromechanical devices into which are fed the mathematical variables in the fire control problem, and which yield solutions in the form of control settings (e.g., gun orders) required for the weapon and launcher to have maximum effect on the target.

All operational gunfire control computers in the U. S. Navy are analog and use either mechanical cams and/or potentiometers and other electronic circuitry to essentially reproduce the minimally essential columns of the gun range table.[3] The later versions are electrical analog using modern solid state circuitry to approximate relatively simple polynomial functions which regenerate portions of the range table. The functions are necessarily simple and either neglect some of the variables which affect projectile flight or only correct for their variations in an approximate fashion. These simplifications are required on the basis of economy and space limitations. For example, none of the analog systems provide inherent corrections for Coriolis or consider the effects due to the interactions of several variations from standard firing conditions occurring at once. It should be noted that under certain conditions provision is made to correct for factors which have smaller influence on the flight of the projectile than those that are neglected. Interaction effects under certain conditions can influence the flight of the 5-inch MARK 41 projectile as much as 5 mils, a value generally considered larger than the dispersion of the round itself.

By the early 1960's, computer technology had advanced to the state that digital computers were being built that could be used to solve the tactical fire control problem. The substitution of digital for analog computers showed promise of much greater flexibility and sophistication and therefore greater accuracy in the solution of the gunfire control problem. For example, in the area of exterior ballistics it permits a much more accurate prediction of the trajectory of the projectile than was possible with the analog computer. Ideally, the best approach to predicting the trajectory of the weapon in the fire control system is to numerically integrate the differential equations of motion within the fire control computer. However, this is an iterative time-consuming process which has not yet been proven practical in the gunfire control computer, especially in light of the high frequency

[2]See Reference 5.
[3]See Reference 6.

of solutions needed to achieve system stability. The most feasible alternative is to develop ballistic functions to approximate the trajectory data obtained from numerical integration of the equations of motion. With the digital computer, this can be done with a degree of accuracy which is practically impossible with the analog computer.

Since its inception, the Naval Weapons Laboratory (NWL) has been the Navy's prime facility for exterior ballistics for surface-launched unguided weapons, including guns. In the early 1960's, NWL was asked by the Naval Ordnance Systems Command (NOSC) to serve as technical advisor to Lockheed Electronics Company (LEC) in the development of the U. S. Navy's first digital gunfire control system. Range tables and specialized ballistic data were provided to Lockheed in support of their efforts which included implementing the range tables in the system. The ballistic functions used in the MARK 86 GFCS are partitioned cubic least-squares polynomials fit to the essential columns of both the surface and anti-aircraft range tables for 5"/54 caliber gun. The ballistic solution is essentially one of applying differential corrections to range and time of flight to obtain gun orders such that the projectile will strike the target under any reasonable non-standard firing conditions that may exist. The solution is analogous to that described in the introductory information to the surface range table.

Initially, the MARK 86 GFCS was designed as a surface only system; therefore, no provision was made to include ballistic solutions for anti-aircraft (AA) targets, that is, targets at non-zero position angles. When the decision was made to add an AA capability, surface-type range tables were fit with polynomials (identical to the procedure for the surface table) for various position angles. To obtain an AA solution with the system, surface-type solutions are obtained for three position angles which bracket the target position angle; quadratic interpolation is then performed among the three surface-type solutions for the position angle of the target.

This procedure requires a large amount of computer storage since it is necessary to store coefficients of the least-squares fits for position angles from zero to 65 degrees in increments of five or ten degrees. Since these functions essentially reproduce the columns in the range table, they contain the deficiencies inherent in the range table; they do not compensate for interaction among the independent variables used in the computation of gun and fuzing orders. Also, in the surface mode, a non-zero target height is compensated for by rotating the surface solution through the position angle. This is acceptable for small position angles, up to approximately six degrees, but introduces fairly large errors at higher position angles.

In 1969, the NWL initiated a modest in-house research program to further investigate techniques for the implementation of gun ballistics in digital gunfire control computers. The program was motivated by the anticipated need for implementing gun ballistics for long-range and guided projectiles, a desire to overcome the shortcomings inherent in the techniques used in the MARK 86 GFCS, and the experience gained in investigating similar problems associated with airborne digital fire control systems.

Rather than attempt to fit the columns of the range table as was done in other approaches and thus retain the deficiencies inherent in the range table, the NWL approach was to first determine a closed-form approximate solution for the basic equations of motion used to mathematically simulate the flight of the projectile and produce the range table. This approach uses an "Effective Drag" which is determined for each data point as a function of slant range, position angle, initial velocity, ballistic density and temperature by substituting into a 20-term expression the values of each of these variables. This Effective Drag is then substituted into the closed-form expression for elevation angle. Time-of-flight is computed similarly using elevation angle and the variables mentioned above.

After deriving the Effective Drag Functions and comparing the accuracy and storage with the functions used in the MARK 86 system, the Naval Ordnance Systems Command (NOSC) funded NWL to tailor the functions to 5"/54 caliber and 3"/50 caliber ammunition for use in the digital version of the MARK 68 GFCS, the most widely used naval gunfire control system. In addition, after discussions with NOSC and LEC personnel, NWL and LEC were funded to investigate the feasibility of replacing the ballistic functions in the MARK 86 system with the Effective Drag Functions. This feasibility study concluded that the effective drag functions should be used in the MARK 86 system in place of the LEC functions. Further information concerning the feasibility study as well as other significant conclusions of the study can be found in Reference 7.

II. TRAJECTORY DATA

The trajectory data used as reference data in the computation of approximating functions were computed using a two-dimensional particle integration program (see Reference 8 for an example of this type of program). The model employs a fourth-order Runge-Kutta scheme to numerically integrate the equations of motion subject to the following assumptions:

1. The earth is flat and non-rotating with gravity varying as a function of altitude.
2. The projectile is a point mass.
3. Drag is the only aerodynamic influence.
4. The atmosphere is Navy Standard (NAST).

The initial conditions (initial velocity, elevation angle), atmospheric conditions (ballistic density, ballistic wind, ballistic temperature), and terminal conditions (flight time for AA mode, target altitude for surface mode) were selected based on the conditions encountered in the tactical use of the MARK 68 and MARK 86 systems. Table 1 lists the type of distribution assumed for each variable as well as the range of conditions used for the functionalization.

TABLE 1

RANGE OF CONDITIONS FOR FUNCTIONALIZATION

Variable	Type of Distribution	Minimum/Maximum	Mean	Standard Deviation
Elevation Angle	Uniform	0°/70°		
Initial Velocity	Uniform	1300 fps/1600 fps (reduced charge 5"/54) 2300 fps/2700 fps (full charge 5"/54) 2450 fps/2750 fps (3"/50)		
Ballistic Density	Normal		100%	3.5%
Ballistic Temperature	Normal		59°F	25°F
Ballistic Range Wind	Normal		0 kts	20 kts
Time-of-Flight (AA only)	Uniform	0/30 sec		
Target Altitude (Surface only)	Uniform	-50/5000 ft		

III. TRAJ COMPUTER MODEL

To generate the trajectory data reflecting the distributions for each variable, a computer model "TRAJ" was developed by NWL personnel. The program is a variation of the basic particle trajectory integration program discussed in Reference 8. The only significant difference between the models is the method used to select initial, atmospheric, and terminal conditions for each trajectory. The basic particle trajectory model requires input values for each of the independent variables whereas the TRAJ programs selects the values for each of these variables based on random sampling from the distributions assumed for each variable. To accomplish the random sampling, the parameters for each of the distributions are input to the model along with the total number of trajectories to be integrated. After integrating these trajectories, the model arranges the trajectory data in ascending order of slant range (surface) or time-of-flight (AA) and prints out the results of the integration along with the initial and atmospheric conditions used to generate the trajectories. In addition to the usual trajectory variables computed by the model (slant range, position angle, time-of-flight, and drift), the effective drag value and the ratio of the tangent of the orientation angle at termination to the tangent of the superelevation angle are printed out. The effective drag value is computed using the following equations:[4]

$$XVAC = \frac{(UM)^2 \sin(2Eg^*)}{(G)(\cos E4^*)}$$

$$N = \frac{XVAC}{Rh4^*}$$

$$FK = \frac{-1 + \sqrt{3N - 2}}{R4^*}$$

If a non-zero value of range wind is generated by the random sampling technique, the model computes all of the above data with respect to the moving air mass. For further explanation of these calculations, see the listing of the TRAJ model given in the appendices. If the target height used to terminate the trajectory is greater than the maximum ordinate of the trajectory, the generated trajectory is discarded and a new set of conditions is generated using the random sampling technique.

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[4] A glossary of terms is given in the appendices.

IV. BALLISTIC FUNCTIONS

The ballistic functions were derived from the differential equations of motion for a point mass. Since these equations have no closed-form solutions for non-vacuum trajectories in terms of elementary functions only, the solution is obtained by approximating the true solution. The functions obtained by this approximation are as follows (The derivation of the superelevation angle function is given in the appendices and the derivation of the time-of-flight function is given in Reference 10.):

$$V4^* = \frac{1}{2}\sin^{-1}\left[\frac{G \cdot N \cdot Rh4^*}{UM^2}\right]$$

$$T4 = SQRT\left[\frac{6 \cdot A \cdot UM \cdot \sin Eg^* - 6 \cdot RV - G \cdot A^2}{2 \cdot G}\right]$$

where

$$N = 1 + (K \cdot RS)(2 + K \cdot RS)/3$$

$$A = \frac{Rh4^*}{UM \cdot \cos Eg^*}$$

To overcome the poor accuracy of the superelevation equation, for long times-of-flight, the quantity "K" is replaced by the term "FK" which is expressed as a least-squares function of initial, atmospheric, and terminal conditions.

AA mode

$$\begin{aligned} FK = {} & K1 + K2 \cdot US + K3 \cdot RS \cdot US \cdot DS + K4 \cdot E4S + K5 \cdot DS + K6 \cdot US \cdot DS \\ & + K7 \cdot RS \cdot DS + K8 \cdot US \cdot TS + K9 \cdot DS \cdot TS + K10 \cdot E4S \cdot RS^2 + \\ & K11 \cdot RS \cdot US \cdot E4S + K12 \cdot RS \cdot E4S + K13 \cdot US \cdot E4S + K14 \cdot RS^3 + \\ & K15 \cdot E4S^3 + K16 \cdot RS \cdot DS \cdot E4S + K17 \cdot RS \cdot E4S^2 + K18 \cdot US \cdot DS \cdot E4S + \\ & K19 \cdot RS \cdot TS + K20 \cdot E4S \cdot US^2 \end{aligned}$$

Surface Mode

$$FK = K1 + K2 \cdot US + K3 \cdot TS + K4 \cdot E4S + K5 \cdot RS \cdot US + K6 \cdot RS \cdot TS$$
$$+ K7 \cdot US \cdot DS + K8 \cdot US \cdot TS + K9 \cdot US \cdot E4S + K10 \cdot RS^2$$
$$+ K11 \cdot RS \cdot E4S^2 + K12 \cdot US \cdot RS^2 + K13 \cdot DS \cdot RS^2 + K14 \cdot E4S \cdot RS^2$$
$$+ K15 \cdot E4S \cdot US^2 + K16 \cdot E4S \cdot DS^2 + K17 \cdot RS^3 + K18 \cdot RS \cdot US \cdot E4S$$
$$+ K19 \cdot RS \cdot DS \cdot E4S + K20 \cdot US \cdot DS \cdot E4S$$

The accuracy of the time-of-flight function is also improved by the addition of a DELT term which is a least-squares function of the initial, atmospheric, and terminal conditions.

AA Mode

$$DELT = L1 + L2 \cdot E4S \cdot RS^2 + L3 \cdot DS \cdot RS^2 + L4 \cdot US \cdot RS^2 + L5 \cdot RS \cdot E4S^2$$
$$+ L6 \cdot RS^3 + L7 \cdot RS \cdot US + L8 \cdot RS \cdot TS$$

Surface Mode

$$DELT = L1 \cdot US + L2 \cdot RS \cdot US + L3 \cdot RS \cdot DS + L4 \cdot US \cdot TS$$
$$+ L5 \cdot DS \cdot TS + L6 \cdot US \cdot RS^2 + L7 \cdot DS \cdot RS^2 + L8 \cdot E4S \cdot RS^2$$
$$+ L9 \cdot RS^3 + L10 \cdot RS \cdot US \cdot E4S$$

In addition to DELT and FK, two other quantities are computed using least-squares expressions. The drift of the projectile due to spin is computed using the following equations:

AA Mode

$$DRS = M1 + M2 \cdot RS \cdot T4S + M3 \cdot RS \cdot E4S + M4 \cdot T4S^2$$
$$+ M5 \cdot T4S \cdot E4S + M6 \cdot E4S^2$$

$$DRIFT = DRS \cdot 10000$$

Surface Mode

$$DRS = M1 \cdot RS + M2 \cdot T4S + M3 \cdot T4S^2$$

$$DRIFT = DRS \cdot 10000$$

The fourth quantity computed using a least-squares expression is the ratio of the tangent of the orientation angle of the projectile at termination to the tangent of the superelevation angle. This quantity is computed only in the surface mode and is used to correct for Coriolis effects. The following expression is used to compute this ratio.

$$Ratio = N1 + N2 \cdot US \cdot RS^2 + N3 \cdot DS \cdot RS^2 + N4 \cdot RS^2 \cdot E4S$$
$$+ N5 \cdot RS \cdot US \cdot DS$$

The cross-terms in the above expressions are used to account for the interaction of the independent variables. In particular, the interaction among initial velocity, ballistic density, and slant range to target is large.

The Effective Drag Functions also have several other advantages compared to the MARK 86 ballistic functions.

1. Interpolation as a function of target position angle is not needed in the AA mode since the position angle is one of the independent variables used in the functions.

2. Non-standard values of initial velocity, ballistic density, and ballistic temperature are considered directly in the solution for the superelevation angle and time-of-flight rather than correcting the calculated values of these two quantities for standard conditions.

3. In the surface mode, target height is considered directly in the solution for the superelevation angle through the terms involving the target position angle.

4. The amount of storage needed for the ballistic functions and the related coefficients is much less than the corresponding storage for the MARK 86 functions.

5. Since fewer partitions of the least-squares functions are needed, the amount of computer time used to find the correct partitions is less than for the MARK 86 system.

To compensate for horizontal range wind, the following procedure is used:

1. The horizontal range of the target is modified using the following equations

$$Rh4^{*} = Rh4 - T4 \cdot Wrh$$

2. The initial velocity of the projectile is modified by the apparent wind velocity.

$$UM = SQRT\left[(U \sin Eg)^2 + (U \cos Eg - Wrha)^2\right]$$

3. After computing a superelevation angle using the equation given previously, the elevation angle is modified using this equation:

$$Eg = \tan^{-1} \frac{UM \cdot \sin Eg^{*}}{UM \cdot \cos Eg^{*} + Wrha}$$

The sequence of calculations for both the AA and surface modes and a glossary of terms are given in the appendices.

In addition to the independent variables discussed above, many of the variables which effect the projectile trajectory can be taken into account using closed-form expressions (i.e., no least-squares coefficients are needed). Lateral winds and the affect of own ship motion perpendicular to the line-of-fire on the trajectory can be considered as described in Reference 11. Non-standard projectile weight can be considered by modifying the initial velocity of the projectile and the ballistic density as described in Reference 11.

V. LEAST-SQUARES PROCEDURES

The expressions previously given for FK, DELT, DRIFT, and RATIO were determined by the BIVOR (Backward Independent Variable Ordering by Regression Sum of Squares) procedure discussed in Reference 12. This procedure ranks least-squares terms according to ascending order of importance. To obtain the expression for FK, a 71-term least-squares fit was carried out using the trajectory data generated by the TRAJ program. The least-squares expression consisted of low powers of each of the six independent variables and products of these powers. By deleting the least important term at each step, the twenty most important terms were selected for inclusion in the final functional form. The same procedure was used to select the final functional forms for DELT, DRIFT, and RATIO. The ranking was carried out using the SELECT computer model coded at NWL. The major difference between SELECT and the model discussed in Reference 12 is that the SELECT program can do least-squares fits and related analyses for several sets of data at one time. This is accomplished by summing the values of the additional regression sum of squares (ARSS) for each term over all the sets of data input to the model. The BIVOR ranking is based on several least-squares fits using the same functional form for each data set. The least-squares coefficients for each data set are given in the appendices.

To attain the functional accuracy needed to adequately approximate the solution to the particle equations of motion, it is necessary to partition the fits as a function of slant range to target. The AA functions required two partitions for both 5"/54 and 3"/50 projectiles. In the surface mode the following number of partitions are used:

5"/54 full charge	3
5"/54 reduced charge	4
3"/50	3

If better accuracy is desired, it is possible to use a larger number of terms for each of the four variables fitted. Terms different from those currently used in the SELECT or RANDOM may be added to the programs with a minimum of new coding.

FUNCTIONAL ACCURACY
AA MODE

Gun	Slant Range (Yds)	RMS in Range Error[1] (Mils)	RMS in Miss Distance[2] (Yds)	RMS in Time-of-Flight (Sec)
5"/54	0-11200	.8	.6	.02
	11200-15000	.8	3.0	.06
	TOTAL	.8	1.8	.04
3"/50	0-8500	1.8	2.4	.04
	8500-11000	2.1	7.6	.10
	TOTAL	1.9	4.8	.07
	OVERALL TOTAL	1.5	3.6	.05

[1]Measured along R4
[2]Measured perpendicular to R4 at aim point

FUNCTIONAL ACCURACY
SURFACE MODE

Projectile	RMS in Range Error[1] (Mils)	RMS in Time-of-Flight (Sec)
5"/54 Full Charge	1.9	.13
5"/54 Reduced Charge	2.5	.04
3"/50	1.8	.04

[1]Measured along R4

VI. FUTURE WORK IN BALLISTIC FUNCTIONALIZATION

As discussed previously, NWL and LEC are currently tasked to modify the MARK 86 tactical program to allow the use of the Effective Drag Functions in place of the cubic polynomials currently used. Since the AA portion of the MARK 86 program currently solves for gun orders and fuzing orders for slant ranges exceeding 15,000 yards, the effective drag functions will be extended to include slant ranges greater than the 15,000 yards limit now imposed. It also may be desirable to include more partitions for the surface mode for the 5"/54 full charge projectile. Since new 5-inch ammunition is currently being added to the list of possible ammunition for both the MARK 68 and MARK 86 systems, it will also be necessary to fit the ballistics data for the new rounds.

In addition to these modifications, the joint NWL-LEC study is also aimed at modifying the MARK 86 program to interface with the 8"/55 major caliber lightweight gun (MCLWG). The trajectory data for the 8-inch projectile will be generated in the system by use of the Effective Drag Functions.

It is envisioned that the Effective Drag Functions can be used in future digital fire control systems for projectiles ranging in diameter from 20 millimeters to 16 inches. There are many advantages to having the same functional form in each of the gunfire systems: (1) Only one set of computations is required to generate the least-squares coefficients for each projectile type; (2) If ballistics for a round are changed, new ballistics can be added with a minimum of effort; (3) When analysts work with the coding of each of several systems, it will not be necessary to be familiar with many different types of ballistics functions.

The anticipated addition of guided projectiles to the naval arsenal of projectiles will require ballistic functions that cause the projectile to pass through the acquisition cone and thus acquire the target. The effective drag functions should work extremely well for this purpose since the basic assumptions used in the derivation of the effective drag functions are compatible with the trajectory data for the guided projectile prior to the actuation of guidance.

REFERENCES

1. *Principles of Naval Ordnance and Gunnery,* Bureau of Naval Personnel Report No. 10783-A (1965).

2. *Range Table for 5-Inch 54-Caliber Guns MARK 16, MARK 18, and MARK 19 Firing FCL(VT) Projectile MARK 41 and MODS (Surface Targets),* NAVORD OP 1182, First Revision, Change 1-6 Inserted, 24 March 1958, Changed 1 August 1970.

3. *Range Table for 5-Inch 54-Caliber Guns MARK 16, and MARK 18 Firing (FCL(VT)) Projectile MARK 41 and MODS (Air Targets),* NAVORD OP 1184, First Revision, 5 April 1957.

4. *Range Table for 5-Inch 54-Caliber Guns Firing Projectile MARK 41 and MODS With Reduced Charges (Surface Targets),* NAVORD OP 3495, 15 January 1967.

5. *First Order, Second Order and Interaction Effects on Range and Time-of-Flight of the 5-Inch Projectile MARK 41,* R. D. Cuddy, NWL Technical Memorandum No. K-12/65.

6. *Computer MARK 47 MOD 11, Description, Operation and Maintenance,* NAVORD OP 3729 Volume 1, 1 July 1969.

7. *Interface Study MK 76 MOD 0 8-Inch Gun Mount/MK 86 Gunfire Control System Final Report,* Lockheed Electronics Company, Inc., LEC Report No. 22-0670-1000 (31 January 1972).

8. *A STRETCH Computer Program to Integrate Particle Trajectories Using Navy Standard Atmosphere,* K. B. Pollock, NWL Technical Memorandum No. K-72/65.

9. *The Groundwork of Practical Naval Gunnery or Exterior Ballistics,* Second Edition, Alger, Philip R., (The United States Naval Institute, Annapolis, Maryland) 1917.

10. *Functionalization of Fragment Trajectory Data,* G. H. Ott, NWL Technical Report No. TR-2224 (October 1968).

11. *Preparation of Exterior Ballistic Tables,* NPG Report No. 1530, NAVORD Report No. 5136, U. S. Naval Proving Ground, Dahlgren, Virginia, 14 March 1958.

12. *DA-MRCA; A FORTRAN IV Program for Multiple Linear Regression,* K. Abt, G. Gemmill, T. Herring and R. Shade, NWL Technical Report No. TR-2035 (March 1966).

APPENDIX A

DERIVATION OF SUPERELEVATION ANGLE EQUATION

DERIVATION OF SUPERELEVATION ANGLE EQUATION

The particle equation for horizontal range is:

$$\frac{d\dot{x}}{dt} = \frac{d^2 x}{dt^2} = -KV^2 \cos\theta \tag{1}$$

where

$K = \frac{1}{2} \rho \gamma C_D$ is the retardation of the particle
ρ is air density
γ is the reciprocal of the ballistic coefficient
C_D is the drag coefficient
V is the velocity of the particle
θ is the orientation angle of the particle.

Substituting ds/dt for V gives

$$\frac{d\dot{x}}{dt} = -KV\cos\theta \frac{ds}{dt} \tag{2}$$

or

$$d\dot{x} = -KV\cos\theta\, ds. \tag{3}$$

Substituting $\dot{x}$ for $V\cos\theta$ in (3) gives

$$d\dot{x} = -K\dot{x}ds. \tag{4}$$

Separating variables gives:

$$\frac{d\dot{x}}{\dot{x}} = -Kds. \tag{5}$$

Integrating (5) and substituting limits gives

$$\log(V \cos \phi) - \log \dot{x} = Ks \tag{6}$$

where

ϕ is the initial value of θ.

$$\log(V \cos \phi/\dot{x}) = Ks , \tag{7}$$

$$V \cos \phi/\dot{x} = e^{Ks} , \tag{8}$$

and

$$\dot{x} = V \cos \phi e^{-Ks} = \dot{x}_0 e^{-Ks} . \tag{9}$$

Also

$$\frac{V^2}{r} = g \cos \theta \tag{10}$$

where

r is the radius of curvature, and
g is the acceleration due to gravity.

Since $V = \dot{x} \sec \theta$ and $r = \frac{-ds}{d\theta}$, equation (10) becomes:

$$\frac{\dot{x}^2 \sec^2 \theta}{-ds/d\theta} = g \cos \theta \tag{11}$$

or

$$\dot{x}^2 \sec^2 \theta = (-g \cos \theta) \frac{ds}{d\theta} . \tag{12}$$

Therefore

$$\sec^2 \theta \, d\theta = \frac{-g \cos \theta \, ds}{\dot{x}^2} \tag{13}$$

Substituting dx for ds cos θ gives:

$$\sec^2 \theta \, d\theta = \frac{-g dx}{\dot{x}^2}. \tag{14}$$

Substituting the expression from (9) into Equation (14) gives:

$$\sec^2 \theta \, d\theta = \frac{-g dx}{V^2 \cos^2 \phi e^{-2Ks}} \tag{15}$$

or

$$\sec^2 \theta \, d\theta = \frac{-g e^{2Ks} dx}{V^2 \cos^2 \phi}. \tag{16}$$

Using the approximation s = x in (16) gives.

$$\sec^2 \theta \, d\theta = \frac{-g e^{2Kx} dx}{V^2 \cos^2 \phi}. \tag{17}$$

Integrating (17) between appropriate limits gives:

$$\tan \theta - \tan \phi = \left[\frac{-g}{2KV^2 \cos^2 \phi}\right] \left[e^{2Kx} - 1\right]. \tag{18}$$

Let

$$e^{2Kx} = 1 + 2Kx + \frac{(2Kx)^2}{2} + \frac{(2Kx)^3}{6}$$

$$e^{2Kx} = 1 + 2Kx + 2K^2x^2 + \frac{4}{3}K^3x^3$$

$$e^{2Kx} - 1 = 2Kx + 2K^2x^2 + \frac{4}{3}K^3x^3$$

or

$$e^{2Kx} - 1 = 2Kx\left[1 + Kx + \frac{2}{3}K^2x^2\right] \tag{19}$$

Substituting this expression into (18) gives:

$$\frac{dy}{dx} = \tan\theta = \tan\phi - \left[\frac{g}{2KV^2\cos^2\phi}\right]\left[2Kx(1 + Kx + \frac{2}{3}K^2x^2)\right] \tag{20}$$

or

$$dy = \left[\tan\phi - \frac{gx}{V^2\cos^2\phi}(1 + Kx + \frac{2}{3}K^2x^2)\right]dx. \tag{21}$$

Integrating (21) gives:

$$y = x\tan\phi - \left[\frac{gx^2}{2V^2\cos^2\phi}\right]\left[1 + \frac{2Kx}{3} + \frac{K^2x^2}{3}\right]. \tag{22}$$

Let $N = 1 + \frac{2Kx}{3} + \frac{K^2x^2}{3}$:

$$y = x\tan\phi - \frac{Ngx^2}{2V^2\cos^2\phi}. \tag{23}$$

Let $y = 0$:

$$x\tan\phi = \frac{Ngx^2}{2V^2\cos^2\phi} \tag{24}$$

$$(2V^2\cos^2\phi)(x\tan\phi) = Ngx^2$$

$$2V^2\cos^2\phi\tan\phi = Ngx \tag{25}$$

$$2V^2\cos\phi\sin\phi = Ngx \tag{26}$$

$$\sin 2\phi = \frac{Ngx}{V^2} . \tag{27}$$

Therefore

$$\phi = \left[\sin^{-1}\left(\frac{Ngx}{V^2}\right)\right] \Big/ 2 \tag{28}$$

where

$$N = 1 + \frac{2Kx}{3} + \frac{K^2 x^2}{3} .$$

APPENDIX B

SEQUENCE OF CALCULATIONS
AA AND SURFACE MODES

SEQUENCE OF CALCULATIONS

AA MODE

$$Rh4^* = Rh4 - T4 \cdot Wrh \quad (1)$$

$$R4^* = SQRT[(Rh4^*)^2 + (Rv)^2] \quad (2)$$

$$E4^* = \tan^{-1} \left[\frac{Rv}{Rh4^*}\right] \quad (3)$$

$$UM = SQRT[(U \sin Eg)^2 + (U \cos Eg - Wrha)^2] \quad (4)$$

(Use best estimates of T4 and Eg available at this time. If no estimates are available, assume Wrha = 0.)

$$\begin{aligned} FK = {} & K1 + K2 \cdot US + K3 \cdot RS \cdot US \cdot DS + K4 \cdot E4S + K5 \cdot DS + K6 \cdot US \cdot DS \\ & + K7 \cdot RS \cdot DS + K8 \cdot US \cdot TS + K9 \cdot DS \cdot TS + K10 \cdot E4S \cdot RS^2 + \\ & K11 \cdot RS \cdot US \cdot E4S + K12 \cdot RS \cdot E4S + K13 \cdot US \cdot E4S + K14 \cdot RS^3 + \\ & K15 \cdot E4S^3 + K16 \cdot RS \cdot DS \cdot E4S + K17 \cdot RS \cdot E4S^2 + K18 \cdot US \cdot DS \cdot E4S + \\ & K19 \cdot RS \cdot TS + K20 \cdot E4S \cdot US^2 \end{aligned} \quad (5)$$

$$N = 1 + (FK \cdot RS)(2 + FK \cdot RS)/3 \quad (6)$$

$$V4^* = 1/2 \sin^{-1} \left[\frac{G \cdot N \cdot Rh4^*}{UM^2}\right] \quad (7)$$

$$Eg^* = E4^* + V4^* \quad (8)$$

$$Eg = \tan^{-1} \left[\frac{UM \cdot \sin Eg^*}{UM \cdot \cos Eg^* + Wrha}\right] \quad (9)$$

$$\text{DELT} = \text{L1} + \text{L2} \cdot \text{E4S} \cdot \text{RS}^2 + \text{L3} \cdot \text{DS} \cdot \text{RS}^2 + \text{L4} \cdot \text{US} \cdot \text{RS}^2 + \text{L5} \cdot \text{RS} \cdot \text{E4S}^2 + \text{L6} \cdot \text{RS}^3 + \text{L7} \cdot \text{RS} \cdot \text{US} + \text{L8} \cdot \text{RS} \cdot \text{TS} \quad (10)$$

$$\text{A} = \frac{\text{Rh4*}}{\text{UM} \cdot \cos \text{Eg*}} \quad (11)$$

$$\text{T4} = \text{SQRT}\left[\frac{6 \cdot \text{A} \cdot \text{UM} \cdot \sin \text{Eg*} - 6 \cdot \text{Rv} - \text{G} \cdot \text{A}^2}{2 \cdot \text{G}}\right] + \text{DELT} \quad (12)$$

SEQUENCE OF CALCULATIONS

SURFACE MODE

$$\text{Ratio} = N1 + N2 \cdot US \cdot RS^2 + N3 \cdot DS \cdot RS^2 + N4 \cdot E4S \cdot RS^2 + N5 \cdot RS \cdot US \cdot DS \quad (1)$$

$$TANW = \text{Ratio} \cdot \tan Eg \quad (2)$$

$$DELX = \frac{18274 \cdot US^2 \cdot \cos(2 \cdot Eg)}{3 + 4 \cdot FK \cdot RS + 3 \cdot FK^2 \cdot RS^2} + D1 \quad (3)$$

$$AG = [0.2431 \cdot T4][.1038 \cdot DELX + 1.8 \cdot RS/TANW] \quad (4)$$

$$BG = [0.3646 \cdot T4 \cdot RS]\left[\frac{3 \cdot \tan Eg + TANW}{\tan Eg + TANW}\right] \quad (5)$$

$$DG = [0.1215 \cdot T4 \cdot RS \cdot \tan Eg]\left[\frac{19 \cdot \tan Eg + TANW}{7 \cdot \tan Eg + 3 \cdot TANW}\right] \quad (6)$$

$$DELXO = AG \cdot \cos L \cdot \sin Az \quad (7)$$

$$DOMEGA = BG \cdot \sin L - DG \cdot \cos L \cos Az \quad (8)$$

$$Rh4^* = Rh4 - DELXO - T4 \cdot Wrh \quad (9)$$

$$R4^* = SQRT[(Rh4^*)^2 + (Rv)^2] \quad (10)$$

$$E4^* = \tan^{-1}\left[\frac{Rv}{Rh4^*}\right] \quad (11)$$

$$Um = SQRT[(U \sin Eg)^2 + (U \cos Eg - Wrha)^2] \quad (12)$$

(Use best estimates of T4, Eg, and FK available in (2), (3), (5), (6), (9), and (12). If none are available, assume Wrh, DELXO, and DOMEGA are zero.)

$$
\begin{aligned}
FK = {} & K1 + K2 \cdot US + K3 \cdot TS + K4 \cdot E4S + K5 \cdot RS \cdot US + K6 \cdot RS \cdot TS \\
& + K7 \cdot US \cdot DS + K8 \cdot US \cdot TS + K9 \cdot US \cdot E4S + K10 \cdot RS^2 \\
& + K11 \cdot RS \cdot E4S^2 + K12 \cdot US \cdot RS^2 + K13 \cdot DS \cdot RS^2 + K14 \cdot E4S \cdot RS^2 \\
& + K15 \cdot E4S \cdot US^2 + K16 \cdot E4S \cdot DS^2 + K17 \cdot RS^3 + K18 \cdot RS \cdot US \cdot E4S \\
& + K19 \cdot RS \cdot DS \cdot E4S + K20 \cdot US \cdot DS \cdot E4S \qquad (13)
\end{aligned}
$$

$$
N = 1 + (FK \cdot RS)(2 + FK \cdot RS)/3 \qquad (14)
$$

$$
\sin 2 = \frac{G \cdot N \cdot Rh4^*}{UM^2} \qquad (15)
$$

(If sin2 is greater than one, limit it to one.)

$$
V4^* = 1/2 \sin^{-1} (\sin 2) \qquad (16)
$$

(If a high angle solution is desired, set $V4^* = 1/2[180° - \sin^{-1} (\sin 2)]$).

$$
Eg^* = E4^* + V4^* \qquad (17)
$$

$$
Eg = \tan^{-1} \left[\frac{Um \cdot \sin Eg^*}{Um \cdot \cos Eg^* + Wrha}\right] \qquad (18)
$$

$$
\begin{aligned}
DELT = {} & L1 \cdot US + L2 \cdot RS \cdot US + L3 \cdot RS \cdot DS + L4 \cdot US \cdot TS \\
& + L5 \cdot DS \cdot TS + L6 \cdot US \cdot RS^2 + L7 \cdot DS \cdot RS^2 + L8 \cdot E4S \cdot RS^2 \qquad (19) \\
& + L9 \cdot RS^3 + L10 \cdot RS \cdot US \cdot E4S
\end{aligned}
$$

$$A = \frac{Rh^*}{Um \cdot \cos Eg^*} \tag{20}$$

$$T4 = SQRT \left[\frac{6 \cdot A \cdot Um \cdot \sin Eg^* - 6 \cdot Rv - G \cdot A^2}{2 \cdot G} \right] + DELT \tag{21}$$

APPENDIX C

GLOSSARY OF TERMS

GLOSSARY OF TERMS

A	Intermediate quantity used in computation of T4
AG	Intermediate Coriolis coefficient
AZ	Azimuth of the line of fire (measured clockwise from the north)
BG	Intermediate Coriolis coefficient
DELT	Intermediate quantity used in computation of T4
DELX	Change in range corresponding to an increase of ten minutes in Eg (Yards)
DELXO	Change in range due to Coriolis effect (Feet)
DG	Intermediate Coriolis coefficient
DOMEGA	Cross range due to Coriolis effect (Feet)
DRIFT	Drift (Feet)
DRS	Drift $\times 10^{-4}$ (Feet)
DS	Ballistic density $\times 10^{-2}$ (Percent of Standard)
D1	Coefficient in DELX expression
Eg	Elevation angle with respect to ground (Degrees)
Eg*	Elevation angle with respect to air (Degrees)
E4*	Aiming position angle (Degrees)
E4S	Aiming position angle (Radians)
FK	Intermediate quantity used in computation of Eg
G	Gravity constant (32.174 Ft/Sec^2)
K1 – K20	Coefficients for FK expression
L	Latitude
L1 – L10	Coefficients for DELT expression

M1 – M5	Coefficients for DRS expression
N	Intermediate quantity used in computation of Eg
N1 – N5	Coefficients for ratio expression
Ratio	Intermediate expression used in computing Coriolis effects
Rh4	Horizontal range to aim point (Feet)
Rh4*	Horizontal range to aim point modified by wind effect (Feet)
RS	Slant range to aim point modified by wind effect $\times 10^{-4}$ (Feet)
Rv	Vertical range to aim point (Feet)
R4	Slant range to aim point (Feet)
R4*	Slant range to aim point modified by wind effect (Feet)
sin2	Sine of twice the superelevation angle
TANW	Tangent of angle to fall
TS	Ballistic temperature $\times 10^{-2}$ (Degrees Fahrenheit)
T4	Projectile time-of-flight to aim point (Sec)
T4S	Projectile time-of-flight to aim point $\times 10^{-2}$ (Sec)
U	Initial velocity of projectile with respect to ground (Ft/Sec)
Um	Initial velocity of projectile with respect to air (Ft/Sec)
US	Initial velocity of projectile with respect to air $\times 10^{-4}$ (Ft/Sec)
V4*	Superelevation angle (Degrees)
Wrh	True horizontal ballistic wind (Ft/Sec)
Wrha	Apparent horizontal ballistic wind (Ft/Sec)
Ws	True horizontal ballistic wind $\times 10^{-2}$ (Knots)

APPENDIX D

COEFFICIENT TABLES

TABLE OF COEFFICIENTS

AA MODE

	5"/54		3"/50	
	0-11200 yards Slant Range	11200-15000 yards Slant Range	0-8500 yards Slant Range	8500-11000 yards Slant Range
K1	-.9810293E-01	-.1874708E-00	.4234776E-00	.3488444E-00
K2	.2544428E-00	.5877715E+00	-.2170355E+01	-.1585319E+01
K3	-.2724356E-01	.1153756E-00	.8540107E+00	.7032495E+00
K4	.4287342E-00	.5430970E+00	-.2514494E-00	-.7887737E+00
K5	.4066069E-00	.5890901E+00	.7784072E+00	.8533952E+00
K6	-.7607970E-00	-.1574866E+01	-.1034142E+01	-.6907776E+00
K7	.1738324E-01	-.7027828E-02	-.9297848E-01	-.1725396E-00
K8	-.1100654E-01	.4833599E-01	.4142487E-00	.7856080E+00
K9	.1377282E-01	.7929818E-02	-.4715971E-01	-.8014711E-01
K10	.2904165E-02	.1208286E-01	.3714500E-01	.1300060E-00
K11	-.2465604E-00	-.8451241E+00	-.1279363E+01	-.4156714E+01
K12	.1197910E-01	.6633662E-01	.1255800E-00	-.1352547E-00
K13	-.2777371E+01	-.4274047E+01	.1783080E+01	.7640870E+01
K14	.3755598E-04	-.2408244E-03	-.4135671E-02	-.1502046E-03
K15	-.9235122E-02	-.2254212E-01	-.3473544E-02	-.5204026E-01
K16	.2838094E-01	.5660594E-01	.9366087E-01	.6819491E+00
K17	.7251661E-02	.1474725E-01	.7283655E-02	.5074930E-01
K18	-.3073384E-00	-.7018579E+00	-.3798729E-00	-.5255411E+01
K19	.1269905E-02	-.8923626E-03	-.1245816E-01	-.3863329E-01
K20	.6224520E+01	.1371892E+02	-.5342851E+00	.9673920E+01
L1	-.9330092E-02	.3839703E-00	.2426971E-00	-.1428936E+01
L2	-.5993651E-01	-.1011252E-00	-.1199946E-00	-.2019259E-00
L3	.4183774E-01	-.8509310E-02	-.5215645E-01	-.2341028E-00
L4	.3654574E-02	.8007668E+00	.3709750E+01	-.3098614E-00
L5	.4870824E-01	.1231386E-00	.6590915E-01	.1642611E-00
L6	.6214550E-03	-.1955255E-01	-.2250537E-00	-.1229106E-01
L7	-.8304742E-01	-.1392877E+01	-.3104506E+01	.6509672E+01
L8	.3393555E-02	-.1643145E-01	-.5360088E-01	-.7440388E-01
M1	.3482418E-03	.3772293E-02	.4170855E-04	.6598455E-02
M2	-.1471266E-01	-.2745239E-01	-.2647575E-01	-.7894141E-01

TABLE OF COEFFICIENTS (Continued)

	5"/54		3"/50	
	0-11200 yards Slant Range	11200-15000 yards Slant Range	0-8500 yards Slant Range	8500-11000 yards Slant Range
M3	.2738276E-02	.5895750E-02	.6164067E-02	.1671360E-01
M4	.4269650E-00	.5473077E+00	.6476893E+00	.1122133E+01
M5	-.6064290E-01	-.9502992E-01	-.9995276E-01	-.1934456E-00
M6	-.3310132E-03	-.3940700E-02	-.1100139E-02	-.7420265E-02

TABLE OF COEFFICIENTS

SURFACE MODE

5"/54 FULL CHARGE

	0-18000 yards Slant Range	18000-24000 yards Slant Range	14500-24000 yards* Slant Range
K1	.3955169E-00	.5669702E+00	-.1704694E-00
K2	-.1912286E+01	-.3534244E+01	.4507427E+01
K3	-.2172905E-01	-.3670860E-01	-.2749037E-01
K4	-.2803963E+01	-.8572506E+01	-.8533351E+00
K5	-.3226089E-01	.2620820E-00	-.1217341E+01
K6	-.2404475E-02	-.5131253E-02	-.1922547E-02
K7	.1089821E+01	.1543458E+01	.4899658E-00
K8	.1749775E-00	.2731868E-00	.1530299E-00
K9	.2349699E+02	.6977835E+02	.1272636E+02
K10	.2371911E-02	-.4980339E-02	.1525784E-01
K11	.2128974E-01	.4630666E-01	-.1664827E-00
K12	.2455250E-01	.1387262E-01	.7428142E-01
K13	.2164224E-03	-.4995185E-02	.1606694E-02
K14	.5628305E-02	.2042015E-01	-.4869881E-02
K15	-.2933482E+02	-.1508217E+03	-.7734495E+02
K16	.1004287E+01	-.1354619E+01	.1123986E-00
K17	-.1071262E-02	.1121990E-04	-.1394350E-02
K18	-.3416361E-00	-.1131332E+01	.2505003E+01
K19	.4430317E-01	.8263510E-01	-.8141508E+00
K20	-.8659542E+01	.9691415E+01	.1692769E+02
L1	.7572007E+00	.9917354E+01	.3534241E+02
L2	-.1071067E+02	-.9947143E+01	-.3416829E+01
L3	.2250318E+01	.1541953E+01	-.3812515E+01
L4	.7172221E+01	-.1404480E+02	-.6125264E+01
L5	-.1951473E+01	.2125157E+01	-.6025834E-01
L6	.2888127E+01	.2886421E+01	-.5432146E+00
L7	-.4459809E-00	-.4308659E-00	.6589226E+00
L8	-.9974401E-01	-.9333276E+00	.4681561E-00
L9	-.3265210E-01	-.2801638E-0 1	-.5810161E-02
L10	.5116443E-01	.1800316E+02	-.1704057E+02

*High-angle partition

TABLE OF COEFFICIENTS (Continued)

	0-18000 yards Slant Range	18000-24000 yards Slant Range	14500-24000 yards* Slant Range
M1	-.2657291E-02	-.1615951E-01	-.2156430E-01
M2	.4156908E-01	.2532693E-00	.3528588E-00
M3	.1815574E-00	.9500279E-01	.2902570E-01
N1	.9191189E+00	.1340461E+01	.1133630E+01
N2	-.2446265E-01	.9275399E-01	.5260185E-01
N3	-.3669022E-02	-.4472610E-01	-.5129406E-01
N4	.1987127E-01	.5253587E-01	.1678999E+00
N5	.1005881E+01	.8647075E+00	.1342037E+01

*High-angle partition

TABLE OF COEFFICIENTS

SURFACE MODE

5"/54 REDUCED CHARGE

	0-7000 yards Slant Range	7000-9000 yards Slant Range	9000-13500 yards Slant Range	7000-13500 yards* Slant Range
K1	.5298128E+00	.1202159E-00	.2826655E-00	-.7421792E+00
K2	-.3934450E+01	-.3309993E-00	-.5596140E+01	.1540729E+02
K3	-.1561971E-00	-.1674386E-00	-.9466058E-01	-.6586182E-01
K4	-.1797008E+02	-.8886847E+01	-.2815730E+01	-.3939762E-00
K5	.3823152E-00	-.1078237E-01	.4734604E+01	-.7041342E+01
K6	-.2544909E-01	-.6320953E-02	.2677492E-03	.7511573E-02
K7	.1948643E+01	1780902E+01	.6738246E+00	.6031804E+00
K8	.1264884E+01	.1072910E+01	.4546266E-00	.1712773E-00
K9	.2505323E+03	.1281992E+03	.4029905E+02	.2441291E+02
K10	-.8957101E-01	-.1169131E-01	-.1126286E-00	.1280071E-00
K11	-.1008650E-00	.3548671E-01	.2144906E-00	-.5780454E+00
K12	.5820816E+00	-.3706394E-02	-.7773864E+00	.9242395E+00
K13	-.1608779E-01	-.1238116E-01	.3467924E-02	.5279097E-02
K14	-.3086801E-02	-.2494991E-00	.3212877E-00	.4976959E-01
K15	-.8940509E+03	-.5395590E+03	-.6852114E+02	-.1818477E+03
K16	.3083025E-00	-.7471392E+00	-.4682051E-00	.3646941E-00
K17	.2159488E-04	.5139764E-02	.2243239E-01	-.2476135E-01
K18	.4008211E+01	.7984475E+01	-.1207549E+02	.4426619E+01
K19	-.5602425E+00	.5728711E-01	-.9943378E-01	-.1679682E+01
K20	.2061799E+01	.7491158E+01	.1112658E+02	.2752567E+02
L1	.7811849E+00	.1045614E+02	-.1795124E+02	-.2947601E+02
L2	-.2800263E+01	.5766946E+01	.8842858E+01	.3014125E+01
L3	.1389815E-00	-.2489663E+01	.1581421E-00	.1148676E+01
L4	-.4497183E-00	-.7774090E+01	-.6966992E+01	-.1046813E+02
L5	-.4123882E-02	.1035831E+01	.1233712E+01	.1567005E+01
L6	.4628736E+01	-.1142702E+01	.2951062E-00	-.3058953E+01
L7	-.3203420E-00	.8058107E+00	-.2294523E-00	-.2975420E-00
L8	-.3412521E-00	.1092594E-00	-.7223061E+00	.8236817E+00
L9	-.1430581E-00	-.1131578E-00	-.3185181E-01	.1249615E-00
L10	.1875993E+01	-.4491435E+01	.1073504E+02	-.1541037E+02
M1	-.3533008E-02	-.6760702E-02	-.1267627E-01	-.1881960E-01
M2	.4561825E-01	.7988161E-01	.1492779E-00	.2039353E-00
M3	.1907201E-00	.1994128E-00	.1620066E-00	.1337699E-00
N1	.9594301E+00	.9225252E+00	.1050865E+01	.1454356E+01
N2	.5544641E+00	.1160196E+00	.4923114E-01	.1853321E+00
N3	-.1597535E+00	-.7929263E-01	-.2162164E-01	-.1884167E+00
N4	.1302047E+00	.1441210E+00	.1523246E+00	.5649786E+00
N5	.2194533E+01	.2047935E+01	.8052037E+00	.3291107E+01

*High-angle partition

TABLE OF COEFFICIENTS

SURFACE MODE

3″/50

	0-7500 yards Slant Range	7500-14200 yards Slant Range	9000-14200 yards* Slant Range
K1	.9972894E+00	.1269381E+01	-.4875150E-00
K2	-.4329356E+01	-.7409070E+01	.1345991E+02
K3	-6021274E-01	-.1221252E-00	-.5220929E-01
K4	-.1048994E+02	-.9322561E+01	-.4927079E+01
K5	-.1499602E-01	.2043580E+01	-.7763816E+01
K6	-.9419808E-02	-.1481877E-01	.2158699E-02
K7	.2133987E+01	.2687206E+01	.3029355E+01
K8	.4405334E-00	.6623383E+00	.1581798E-00
K9	.8209066E+02	.7005917E+02	.5456838E+02
K10	-.5925505E-02	-.1004642E-00	.2144224E-00
K11	-.5723983E-01	.5757654E-01	-.5734877E+00
K12	.1540559E-00	-.2100219E-00	.1047363E+01
K13	.5740481E-01	.9732245E-03	-.2429330E-01
K14	-.1439001E-01	.1546526E-00	-.2474639E-01
K15	-.1566121E+03	-.1127932E+03	-.1460537E+03
K16	.4472181E+01	-.3886304E-00	-.1067673E+01
K17	-.2340028E-01	.1453335E-01	-.3850347E-01
K18	.8741858E+01	-.4501337E+01	.3077926E+01
K19	-.2226840E+01	.3944278E-00	-.1607513E+01
K20	-.1827209E+02	.3684374E-00	.2229303E+02
L1	.5494928E+00	.3971734E+01	.1463613E+02
L2	-.6203279E+01	-.7236301E+00	-.1614197E+02
L3	.1107009E+01	-.6270852E+00	-.1149805E+01
L4	.1432898E+01	-.2510048E+01	-.3478743E+01
L5	-.4216346E-00	.4263921E-00	.6707173E+00
L6	.4167495E+01	.1042376E+01	.2648430E+01
L7	-.4582454E-00	.1176264E-00	.8012168E+00
L8	-.4837642E-00	-.7669436E+00	.3390402E-00
L9	-.1492970E-00	-.5601244E-01	-.1008407E-00
L10	.3147546E+01	.6247304E+01	-.9377208E+01

*High-angle partition

TABLE OF COEFFICIENTS (Continued)

	0-7500 yards Slant Range	7500-14200 yards Slant Range	9000-14200 yards* Slant Range
M1	-.2179687E-03	-.9201811E-02	-.3402695E-01
M2	-.2067184E-02	.1073744E-00	.4031741E-00
M3	.2951480E-00	.3104029E-00	.9920955E-01
N1	.8736376E+00	.1255767E+01	.1353942E+01
N2	-.8522887E-01	.9501215E-01	.3830326E+00
N3	-.3916639E-02	-.7664564E-01	-.2977684E+00
N4	.1339467E+00	.1909898E+00	.9398517E+00
N5	.2333159E+01	.1736291E+01	.3498572E+01

*High-angle partition

APPENXIX E

COMPUTER LISTING FOR "TRAJ" PROGRAM

```
      PROGRAM TRAJ(INPUT,OUTPUT,TAPE1)
C**********************************************************************C
C                        RANDOM TRAJECTORY GENERATOR                   C
C                                                                      C
C        THIS PROGRAM GENERATES TRATECTORY END-POINTS USING UNIFORMLY ORC
C     NORMALLY DISTRIBUTED INITIAL, ATMOSPHERIC, AND TERMINAL CONDITIONSC
C     THE PARAMETERS FOR THESE DISTRIBUTIONS ARE INPUT ON CARD TYPE 4.  C
C                                                                      C
C     INITIAL VELOCITY, QUADRANT ELEVATION, AND TERMINAL TIME (AA MODE) C
C     OR ALTITUDE(SURFACE MODE) ARE ASSUMED TO BE UNIFORMLY DISTRIBUTED C
C     WHILE BALLISTIC TEMPERATURE, DENSITY, AND RANGE WIND ARE ASSUMED  C
C     TO BE NORMALLY DISTRIBUTED.                                      C
C                                                                      C
C        DATA CAN BE STACKED USING KSTOP CONTROL (SEE CARD TYPE 4)     C
C        THE DATA IS PUNCHED ONTO CARDS WHICH ARE USED AS INPUT TO THE C
C     SELECT   AND  RANDOM  PROGRAMS. THE WRITTEN OUTPUT IS AN EXACT   C
C     DUPLICATION OF THE DATA PUNCHED ON CARDS.                        C
C                                                                      C
C                               INPUT GUIDE                            C
C                                                                      C
C     CARD TYPE 1 FORMAT(12F6.4) (24 CARDS)                            C
C     COLS.  1-72 VAA   144 VALUES OF MACH NUMBER            (12 CARDS) C
C            1-72 DRAG  144 VALUES OF DRAG COEFFICIENT (CD)  (12 CARDS) C
C                                                                      C
C     CARD TYPE 2 FORMAT(5A10,3F10.5)                                  C
C     COLS.  1-50 WID   WEAPON IDENTIFICATION - PRINTOUT ONLY          C
C           51-60 CANS  DRIFT CONSTANT (FT*FT/SEC*SEC*SEC)             C
C           61-70 DTO   INTEGRATION INTERVAL (SEC)                     C
C           71-80 DUM   INITIAL VALUE FOR RANDOM NUMBER GENERATOR      C
C                                                                      C
C     CARD TYPE 3 FORMAT(I10, F10.5, 6I10)                             C
C     COLS.  1-10 ITYPE =1 SURFACE        =2 AA                        C
C           11-20 GAM   NOMINAL RECIPROCAL BALLISTIC COEFFICIENT       C
C           21-30 NPOINT NUMBER OF TRAJECTORIES TO BE GENERATED        C
C                                                                      C
C     CARD TYPE 4 FORMAT(6F10.5/6F10.5, I10) (TWO CARDS)               C
C     COLS.  1-10 IVMIN MINIMUM INITIAL VELOCITY (FT/SEC)              C
C           11-20 IVMAX MAXIMUM INITIAL VELOCITY (FT/SEC)              C
C     FIRST 21-30 EGMIN MINIMUM QUADRANT ELEVATION (DEG)               C
C     CARD  31-40 EGMAX MAXIMUM QUADRANT ELEVATION (DEG)               C
C           41-50 AVETK AVERAGE BALLISTIC TEMPERATURE (DEG. F.)        C
C           51-60 RMSTK RMS IN  BALLISTIC TEMPERATURE (DEG. F.)        C
C                                                                      C
C     COLS.  1-10 AVED  AVERAGE BALLISTIC DENSITY (PER CENT OF STANDARD)C
C           11-20 RMSD  KMS IN  BALLISTIC DENSITY (PER CENT OF STANDARD)C
C    SECOND 21-30 AVEWX AVERAGE BALLISTIC RANGE WIND (KNOTS)           C
C     CARD  31-40 RMSWX RMS IN  BALLISTIC RANGE WIND (KNOTS)           C
C           41-50 TIMIN MINIMUM TERMINAL ALTITUDE(SURFACE) OR TIME(AA) C
C           51-60 TIMAX MAXIMUM TERMINAL ALTITUDE(SURFACE) OR TIME(AA) C
C           61-70 KSTOP =1 READ IN NEW TYPE 1 CARD                     C
C                       =2 READ IN NEW TYPE 2 CARD                     C
C                       =3 READ IN NEW TYPE 3 CARD                     C
C                       =4 READ IN NEW TYPE 4 CARD                     C
C                       =5 STOP (LAST CARD IN DATA BLCK)               C
C**********************************************************************C
```

```
      COMMON /ONE/ATMOS,DFN,DRIFT,PA,THETA,DENSE
      COMMON /TWO/DEIN(7),DEOUT(7),H,ZMAX
      COMMON /THREE/CM,DRAGC,DRAG(144),VAA(144)
      COMMON /FOUR/GAMMA,QE1,QE2
      COMMON /FIVE/KOUNT, NPOINT
      COMMON /SIX/VA,ICONT,TK,WX,VO
      DIMENSION WID(5), WID2(2)
      EQUIVALENCE (TTER, ZTER)
      REAL IVMIN,IVMAX,IVAVE,IVDEL
      DATA (WID2(I), I = 1, 2) /10HALT.  ALT., 10HTIME  TIME/
      DATA TWOPI /6.2831853/
  500 FORMAT (50X, 17HEXECUTION TIME = , F8.2, 8H SECONDS)
 1000 FORMAT (11F12.6)
 1004 FORMAT (29X,50HEFFECTIVE ANGLE  DRIFT SLANT   TIME OF ELEV. INIT.,
     1        29H  BALL. BALL. RANGE  POSITION/29X,17HDRAG      OF FALL,
     2       5X,53HRANGE   FLIGHT  ANGLE VEL.   DENS. TEMP. WIND   ANGLE
     3       /29X, 45HFEET**-1  RATIO  FEET  FEET    SEC.    RAD.  ,
     4       30HFT/SEC P.C.  DEG F KNOTS  RAD.//17X,14HSCALE FACTOR  ,
     5       56H(1000)    (1)   (.0001)(.0001)  (.01)    (1)  (.0001) (.01)
     6      ,17H(.01) (.01)    (1)/)
 1005 FORMAT (12F6.4)                                                   PAR00050
 1006 FORMAT (1H1, 40X, 42HTRAJECTORY DATA GENERATED FOR USE IN FIRE ,
     1        15HCONTROL SYSTEMS/51X, 24H(USING RANDOM SELECTION ,
     2        10HTECHNIQUE)///59X, 18HDRAG FUNCTION USED//4X,
     3        8(3X,4HMACH,4X,5HDRAG )/)
 1007 FORMAT (4X,16F8.4)
 1008 FORMAT (/50X,6HWEAPON,25X, 25HDRIFT   TIME   GENERATIVE/
     1        46X, 14HIDENTIFICATION, 19X, 24HCONSTANT  STEP      VALUE//
     2        28X, 5A10, F8.1, F8.3, 2X, F12.6/)
 1009 FORMAT (/29X,8HITYPE = , I1, 28H (1=SURFACE, 2=AA)   GAMMA =,F8.5,
     1          2X,25HNUMBER OF TRAJECTORIES = , I4//)
 1010 FORMAT (5A10, 3F10.5)
 1011 FORMAT (1H0)                                                      PAR00110
 1012 FORMAT (I10, F10.5,6I10)
 1013 FORMAT (6F10.5/6F10.5,I10)
 1014 FORMAT (1H1)
 1015 FORMAT (1H0, 38X, 44HSTATISTICAL PARAMETERS USED IN GENERATION OF,
     1        16H TRAJECTORY DATA//29X, 28HMIN.   MAX.   MIN.   MAX.   ,
     2        49HAVE.   RMS    AVE.   RMS    AVE. RMS    MIN.  MAX./
     3        29X, 49HI.V.   I.V.   THETA  THETA  TEMP.  TEMP.  DENS.  ,
     4        18HDENS. WIND WIND   ,A10//
     5        27X, 2F7.0, 4F7.2, F6.0, F7.0, 2F5.0,1X, 2F7.0)
      XXX = SECOND(TTT)
C
C   **** READ INPUT DATA                                    ****
C
  100 READ 1005,(VAA(I),I=1,144),(DRAG(I),I=1,144)                      PAR00180
      PRINT 1006
      PRINT 1007, (VAA(I), DRAG(I),I=1,144)
    1 READ 1010, WID, CANS, DTO, DUM
      PRINT 1008, WID, CANS, DTO, DUM
      JGO=1                                                             PAR00210
    3 READ 1012, ITYPE, GAM, NPOINT
      PRINT 1009, ITYPE, GAM, NPOINT
      GAMM = GAM
```

```
    4 READ 1013, IVMIN, IVMAX, EGMIN, EGMAX, AVETK, RMSTK, AVED, RMSD,
     1            AVEWX, RMSWX, TIMIN, TIMAX, KSTOP
      PRINT 1015, WID2(ITYPE),
     1             IVMIN, IVMAX, EGMIN, EGMAX, AVETK, RMSTK, AVED, RMSD,
     2             AVEWX, RMSWX, TIMIN, TIMAX
      TIDEL =  TIMAX - TIMIN
      EGDEL =  EGMAX - EGMIN
      IVDEL =  IVMAX - IVMIN
      PRINT 1014
      PRINT 1004
      KOUNT = 0
      KOUNT2 = 0
C                                                                  ****
C  **** INITIALIZE RANDOM NUMBER GENERATOR
C
      CALL RANSET(DUM)
      CALL RANGET(DUM)
C                                                                  ****
C  **** GENERATE INITIAL, ATMOSPHERIC, AND TERMINAL CONDITIONS
C
   31 RAN1 = RANF(DUM)
      VO = IVMIN + IVDEL*RAN1
      RAN1 = RANF(DUM)
      THETAD = EGMIN + EGDEL*RAN1
      THETA = THETAD*.0174533
C                                                                  ****
C  **** MODIFY GAMMA FOR MARK 41 REDUCED CHARGE ONLY
C
      IF (ABS(GAM - .36364).LE. .0001 .AND. THETAD .GT. 30.)
     1    GAMM = 1./(2.994 - .464096*THETA)
      RAN1 = RANF(DUM)
      RAN2 = RANF(DUM)
      ANGLER = TWOPI*RAN2
      DENSE =(AVED   + RMSD *SQRT(-2*ALOG(1.-RAN1))*SIN(ANGLER))*.01
C
C  **** SCALE GAMMA BY MULTIPLYING BY GENERATED BALLISTIC DENSITY  ****
C
      GAMMA = DENSE*GAMM
      RAN1 = RANF(DUM)
      RAN2 = RANF(DUM)
      ANGLER = TWOPI*RAN2
      TM     = AVETK + RMSTK*SQRT(-2*ALOG(1.-RAN1))*SIN(ANGLER)
      RAN1 = RANF(DUM)
      RAN2 = RANF(DUM)
      ANGLER = TWOPI*RAN2
      WX     =(AVEWX + RMSWX*SQRT(-2*ALOG(1.-RAN1))*SIN(ANGLER))*1.687836
      RAN1 = RANF(DUM)
      TTER = TIMIN + TIDEL*RAN1
      KOUNT2 = KOUNT2 + 1
      KTOP =-1
C
C  **** SET UP INITIAL VALUES FOR FIRST ENTRY INTO RUNGE-KUTTA     ****
C
   21 VA = VO                                                      PA20J331
      TK=.55556*TM+255.222
```

```
      DEOUT(1)=1.                                                      PAR00340
      DEIN(1) = 0.
      DEIN(2) = 0.
      DEIN(3) = 0.
      DEIN(4)=VA*COS(THETA)                                            PAR00380
      DEIN(5)=VA*SIN(THETA)                                            PAR00390
      DEIN(6)=0.                                                       PAR00391
      DEIN(7)=0.                                                       PAR00392
      H=0.                                                             PAR00400
      ICONT=1
      CALL RUNKUT
      ICONT=2
  101 IGO=1                                                            PAR00450
      CALL RUNKUT
      H=DTO                                                            PAR00451
  102 CALL RUNKUT                                                      PAR00470
  111 GO TO (1119, 1112) ITYPE
C
C   **** TERMINATE TRAJECTORY ON TIME (AA MODE ONLY)              ****
C
 1112 IF (DEIN(3)) 31, 31, 1111
 1111 IF (DEIN(1) + H - TTER) 102, 1117, 1115
 1115 H=TTER-DEIN(1)
 1117 CALL RUNKUT
      IF (DEIN(3)) 31, 113, 113
C
C   **** TERMINATE TRAJECTORY ON ALTITUDE (SURFACE MODE ONLY)     ****
C
 1119 IF (DEIN(5)) 1121, 102, 102
 1121 IF (KTOP) 1122, 1122, 1120
 1122 KTOP = 1
C
C   **** CHECK TO BE SURE THAT MAXIMUM ORDINATE IS GREATER THAN   ****
C   **** TERMINAL ALTITUE-----IF NOT, DISCARD TRAJECTORY          ****
C
      IF (DEIN(3) - ZTER) 31, 113, 102
 1120 IF(DEIN(3)-ZTER)1125,113,102                                     PAR00621
 1125 H=-(DEIN(3)-ZTER)/DEIN(5)                                        PAR00630
      CALL RUNKUT                                                      PAR00631
      IF(ABS(DEIN(3)-ZTER)-.1)113,113,1125
  114 CONTINUE
C
C   **** COMPUTE DRIFT                                            ****
C
  113 DRIFT=CANS*(DEIN(2)*DEIN(6)-DEIN(7))
      KOUNT = KOUNT + 1
      CALL PRTOUT
C
C   **** CHECK TO SEE IF ENOUGH TRAJECTORIES HAVE BEEN GENERATED  ****
C
  236 IF (KOUNT .LT. NPOINT ) GO TO 31
C
C   **** PRINT RUNNING TIME                                       ****
C
      YYY = SECOND(TTT)
```

```
      GAR = YYY - XXX
      PRINT 500, GAR
C
C   **** MONITOR KSTOP TO SEE WHICH TYPE CARD IS TO BE READ NEXT     ****
C
      GO TO (100, 1, 3, 4, 999) KSTOP
  999 STOP
      END
```

```
      SUBROUTINE PRTOUT
      COMMON /ONE/ATMOS,DFN,DRIFT,PA,THETA,DENSE
      COMMON /TWO/DEIN(7),DEOUT(7),H,ZMAX
      COMMON /THREE/CM,DRAGC,DRAG(144),VAA(144)
      COMMON /FOUR/GAMMA,QE1,QE2
      COMMON /FIVE/KOUNT, NPOINT
      COMMON /SIX/VA,ICONT,TK,WX,VO
      DIMENSION SAVE (11,  1000)
      PA = ATAN(DEIN(3)/DEIN(2))
      COSPA = COS(PA)
C
C   **** MODIFY TRAJECTORY DATA TO ACCOUNT FOR RANGE WIND EFFECT    ****
C
      THET  = ATAN(VO*SIN(THETA)/(VO*COS(THETA)-WX))
      VO = SQRT((VO*SIN(THETA))**2 + (VO*COS(THETA) - WX)**2)
      THETA = THET
      DEIN(2) = DEIN(2)  - WX*DEIN(1)
      PA = ATAN(DEIN(3)/DEIN(2))
      COSPA = COS(PA)
      THEO = THETA - PA
      SAVEX = DEIN(2)
C
C   **** COMPUTE VACUUM RANGE                                          ****
C
    2 XVAC = VO*VO*SIN(2.*THEO)*.031080/COSPA
      DEIN(2) = SQRT(DEIN(2)**2 + DEIN(3)**2)
      XX = 1./DEIN(2)
      FN = XVAC*XX
      ROOT = SQRT(3.*FN - 2.)
C
C   **** COMPUTE EFFECTIVE DRAG                                        ****
C
      FK = (-1. + ROOT)*XX*10000.
C
C   **** SCALE QUANTITIES FOR PRINTOUT AND PUNCHING                    ****
C
      DRIFT= DRIFT*.0001
      X = DEIN(2)*.C001
    4 VCS = VO*.0001
      TF = DEIN(1)*.01
      TKS = (TK - 255.222)/ 55.556
      WXS = WX*.01/1.687806
C
C   **** COMPUTE RATIO OF TANS OF ANGLE OF FALL AND ELEVATION ANGLE ****
C
      FX = ATAN2(DEIN(5), DEIN(4)) - PA
      FN =-TAN(FX)/TAN(THEO)
C
C   **** ARRANGE TRAJECTORIES IN ASCENDING VALUES OF SLANT RANGE    ****
C
      I = 1
      IF (KOUNT - 1) 65, 9, 65
   65 KM1 = KOUNT - 1
      DO 7 I = 1, KM1
      IF (X .LT. SAVE(4, I)) GO TO 8
```

```
      7 CONTINUE
        I = KOUNT
        GO TO 9
      8 KI = KOJNT - I
        K1 = KOUNT + 1
        DO 85 J = 1, KI
        DO 85 K = 1, 11
        K1MJ = K1 - J
        KOMJ = KOUNT - J
     85 SAVE(K,K1MJ) = SAVE(K,KOMJ)
      9 SAVE(1, I) = FK
        SAVE(2, I) = FN
        SAVE(3, I) = DRIFT
        SAVE(4, I) = X
        SAVE(5, I) = TF
        SAVE(6, I) = THEO
        SAVE(7, I) = VOS
        SAVE(8, I) = DENSE
        SAVE(9, I) = TKS
        SAVE(10,I) = WXS
        SAVE(11,I) = PA
        IF (KOUNT - NPOINT) 5, 95, 95
C
C     **** PRINT AND PUNCH TRAJECTORY DATA                          ****
C
     95 DO 99 I = 1, NPOINT
     99 PRINTб,(SAVE(J, I), J = 1, 11)
        DO 98 I = 1, NPOINT
     98 WRITE (1,3)  (SAVE(J, I), J = 1, 11)
      6 FORMAT(31X,F6.5,F7.4,F7.4, F7.4,  F8.5,F7.4,1X,F6.5,F6.3,F6.3,F5.3
       1          ,F7.4, F14.5)
      3 FORMAT (   F7.5,F7.4,F7.4, F7.4,  F8.5,F7.4,1X,F6.5,F6.3,F6.3,F5.3
       1          ,F7.4)
      5 RETURN                                                     PRT00260
        END
```

```
      SUBROUTINE  PRTOUT                                      CDC 6600 FTN V3.0-P308 OPT=1  07/14/72  15.32.34.      PAGE      3

      SYMBOLIC REFERENCE MAP

ENTRY POINTS
    1  PRTOUT

VARIABLES        SN  TYPE             RELOCATION
    0  ATMOS         REAL                   ONE              0   CM       REAL                 THREE
  260  COSPA         REAL                                    3   DETN     REAL       ARRAY     TWO
    5  DENSE         REAL                   ONE              2   DEOUT    REAL       ARRAY     TWO
    1  DFN           REAL                   ONE              2   DRAG     REAL       ARRAY     THREE
    1  DRAGC         REAL                   THREE            2   DRIFT    REAL                 ONE
  270  FK            REAL                                  265   FN       REAL
  276  FX            REAL                                    0   GAMMA    REAL                 FOUR
   16  H             REAL                   TWO            277   I        INTEGER
    1  ICONT         INTEGER                SIX            303   J        INTEGER
  304  K             INTEGER                               301   KI       INTEGER
  300  KM1           INTEGER                               306   KOMJ     INTEGER
    0  KOUNT         INTEGER                FIVE           302   K1       INTEGER
  305  K1MJ          INTEGER                                 1   NPOINT   INTEGER              FIVE
    3  PA            REAL                   ONE              1   OE1      REAL                 FOUR
    2  OE2           REAL                   FOUR           267   ROOT     REAL
  307  SAVE          REAL          ARRAY                   263   SAVEX    REAL
  273  TF            REAL                                  261   THET     REAL
    4  THETA         REAL                   ONE            262   THEO     REAL
    2  TK            REAL                   SIX            274   TKS      REAL
    0  VA            REAL                   SIX            222   VAA      REAL       ARRAY     THREE
    4  VO            REAL                   SIX            272   VOS      REAL
    3  WX            REAL                   SIX            275   WXS      REAL
  271  X             REAL                                  264   XVAC     REAL
  265  XX            REAL                                   17   ZMAX     REAL                 TWO

FILE NAMES        MODE
      OUTPUT      FMT                       TAPE1      FMT

EXTERNALS         TYPE    ARGS
      ATAN        REAL      1 LIBRARY                          ATAN2    REAL       2 LIBRARY
      COS         REAL      1 LIBRARY                          SIN      REAL       1 LIBRARY
      SQRT        REAL      1 LIBRARY                          TAN      REAL       1 LIBRARY

STATEMENT LABELS
    0  2            INACTIVE             236  3        FMT                        0  4          INACTIVE
  224  5                                 226  6        FMT                        0  7
  127  8                                 152  9                                   0  65         INACTIVE
    0  85                                  0  95          INACTIVE                0  98
    0  99

COMMON BLOCKS    LENGTH
      ONE           6
      TWO          16
      THREE       290
      FOUR          3
      FIVE          2
      SIX           5
```

```
STATISTICS
  PROGRAM LENGTH  25577B   11199
   COMMON LENGTH    502B     322
```

```
      SUBROUTINE RUNKUT
C
C
C
C    **** THIS RUNGE-KUTTA SUBROUTINE IS TAKEN DIRECTLY FROM THE      ****
C    **** BASIC PARTICLE MODEL FOR PROJECTILES. IT CURRENTLY USES     ****
C    **** NAST ATMOSPHERE ONLY. FOR A FURTHER DISCUSSION OF THE       ****
C    **** SUBROUTINE, SEE TECHNICAL MEMORANDUM NUMBER K-72/65.        ****
C
C
C
      COMMON /TWO/DEIN(7),DEOUT(7),H,ZMAX
      COMMON /THREE/CM,DRAGC,DRAG(144),VAA(144)
      COMMON /FOUR/GAMMA,QE1,QE2
      COMMON /SIX/VA,ICONT,TK,WX,VO
      DIMENSION DE1(7),DE2(7)                                           RUN00040
 1008 FORMAT (49H COMPUTED MACH NO. EXCEEDS MACH NO. OF DRAG TABLE)     RUN00050
 1009 FORMAT (8E15.8)                                                   RUN00051
      M1=4
      JGO=ICONT
      GO TO (300,67),JGO
   67 M1=1
   68 DO 298 I=1,7
      GO TO (294,295,296,297,299),M1
  294 DE1(I)=DEIN(I)
      DE2(I)=DEOUT(I)*H
      E1=DE2(I)*.5
      GO TO 298
  295 E1=DEOUT(I)*.5*H
      DE2(I)=DE2(I)+4.*E1
      GO TO 298
  296 E1=DEOUT(I)*H
      DE2(I)=DE2(I)+E1+E1
      GO TO 298
  297 E1=(DE2(I)+DEOUT(I)*H)/6.
  298 DEIN(I)=DE1(I)+E1
  300 XW=DEIN(4)-WX
      VA=SQRT(XW*XW+DEIN(5)*DEIN(5))
      T=TK-.001981203*DEIN(3)
      CS=1120.*SQRT(T/288.)
      CM=VA/CS
      RHO=.0751366*EXP(-.00003158*DEIN(3))
 2114 I=1
      IF(CM-VAA(I))2115,2115,2116
 2115 DRAGC=DRAG(I)
      GO TO 2119
 2116 DO 2117 I=2,144
      IF(CM-VAA(I))2118,2115,2117
 2117 CONTINUE
      PRINT 1008
      PRINT 1009,(DEIN(I),I=1,5),VA,CS,CM,RHO
      STOP
 2118 DRAGC=DRAG(I-1)+((CM-VAA(I-1))/(VAA(I)-VAA(I-1)))*(DRAG(I)-DRAG(I-
     11))
 2119 DRAGC=.39269675*DRAGC
```

```
      CONS=-GAMMA*RHO*VA*DRAGC/144.
      DEOUT(2)=DEIN(4)
      DEOUT(3)=DEIN(5)
      DEOUT(4)=CONS*X4
      DEOUT(5)=CONS*DEIN(5)-32.152
      DEOUT(6)=1./(VA*VA)
      DEOUT(7)=DEIN(2)/(VA*VA)
      M1=M1+1
      GO TO 68
  299 RETURN
      END
```

APPENDIX F

COMPUTER LISTING FOR "SELECT" PROGRAM

```
      PROGRAM SELECT(INPUT,OUTPUT,TAPE2,TAPE3)
C***********************************************************************
C
C
C                        ****  SELECT  ****
C
C        THIS PROGRAM SELECTS THE TERMS WHICH ARE MOST NEEDED STATISTICALLY
C     TO FIT A SET OF DATA IN THE LEAST SQUARES SENSE.  THE MODEL USES
C     THE BIVOR (BACKWARD INDEPENDENT VARIABLE ORDERING BY REGRESSION
C     SUM OF SQUARES) PROCESS DESCRIBED IN NWL TECHNICAL REPORT NO. 2035.
C
C        THIS PROGRAM DIFFERS FROM THE DA-MRCA PROGRAM DESCRIBED IN TR-2035
C     IN THAT THE BIVOR PROCESS IS USED FOR MORE THAN ONE SET OF DATA AT
C     A TIME. THIS IS ACCOMPLISHED BY SUMMING THE VALUES OF THE ADDITIONAL
C     REGRESSION SUM OF SQUARES(ARSS) CORRESPONDING TO EACH TERM OVER ALL
C     THE SETS OF DATA INPUT TO THE MODEL.
C
C        THE MODEL FIRST DOES A LEAST-SQUARES FIT USING THE TERMS DESCRIBED
C     TO THE MODEL BY CARD TYPE 3.  AT THE TIME THE FIT IS DONE, THE MODEL
C     COMPUTES THE ARSS FOR EACH TERM AND DETERMINES THE TERM WITH MINIMUM
C     VALUE OF ARSS. A NEW FIT IS THEN DONE WITH THAT TERM DELETED.  THIS
C     PROCESS IS REPEATED UNTIL THE NUMBER OF TERMS REMAINING EQUALS IKEEP
C     (INPUT ON CARD TYPE 1)
C
C        THE FORMAT FOR CARD TYPE 5 DESCRIBING INPUT DATA POINTS IS IDENTICAL
C     TO THE FORMAT FOR THE CARDS PUNCHED BY THE TRAJ PROGRAM.  THESE CARDS
C     CAN BE USED DIRECTLY OR CARDS CAN BE PUNCHED BY HAND TO USE AS DATA
C     POINTS FOR THE MODEL. (FOR A PARTICULAR TYPE OF FIT, NOT ALL VARIABLES
C     ARE READ INTO MEMORY.)
C
C        FIVE DIFFERENT TYPES OF FITS CAN BE COMPUTED DEPENDING ON THE
C     VALUE OF ITYPE---SEE INPUT GUIDE FOR DETAILS.
C
C        TO DETERMINE WHICH TERMS ARE AVAILABLE FOR USE IN THE FIT FUNCTION,
C     SEE THE SECTION OF CODING ENTITLED **** DEFINE TERMS FOR FIT AND
C     EVALUATION ****.  ADDITIONAL TERMS CAN BE ADDED TO THE MODEL BY A
C     SIMPLE CHANGE IN THE CODING.
C
C        TWO TEMPORARY DISK FILES (TAPE2 AND TAPE3) ARE USED TO STORE THE
C     ELEMENTS OF THE NORMAL MATRIX AT EACH STEP IN THE BIVOR PROCESS.
C     THIS SIMPLIFIES THE CONSTRUCTION OF THE NORMAL MATRIX AT THE NEXT
C     STEP IN BIVOR.
C
C        IF A *DELT* FIT (ITYPE = 2) IS DONE, THE MODEL WILL COMPUTE THE
C     VALUE OF DELT TO BE USED IN THE FIT FROM THE DATA ON CARD TYPE 5.
C
C        IF A *DRIFT* FIT (ITYPE= 3) IS DONE, TIME OF FLIGHT IS USED AS AN
C     INDEPENDENT VARIABLE INSTEAD OF BALLISTIC RANGE WIND.
C
C        IF INT = 1, THE *ELANG*, *DEGOX*, AND *ANFAL* ARRAYS ARE NOT
C     USED.---THUS, A FIT CAN BE DONE FOR PROJECTILES OTHER THAN THOSE
C     COVERED BY THE ID CONTROL BY NOT USING WEIGHTS IN CONSTRUCTING THE
C     NORMAL MATRIX.  IN THIS CASE, SET ID TO SOME VALUE LESS THAN TEN.
C
C***********************************************************************
```

```
C*****************************************************************************C
C                                                                             C
C                            INPUT GUIDE                                      C
C                                                                             C
C     CARD TYPE 1 FORMAT(16I5)                                                C
C     COLS.   1- 5 KSETS NUMBER OF DATA SETS TO BE USED IN FIT                C
C             6-10 TWT   (ONLY USED IF ITYPE = 1)                             C
C                        =1 MINIMIZE EFFECTIVE DRAG ERROR                     C
C                        =2 MINIMIZE MIL ERROR IN SLANT RANGE                 C
C                        =3 MINIMIZE MISS DISTANCE                            C
C            11-15 ITYPE =1 EFFECTIVE DRAG FIT                                C
C                        =2 DELT FIT                                          C
C                        =3 DRIFT FIT                                         C
C                        =4 RATIO FIT                                         C
C                        =5 TOTAL TIME OF FLIGHT FIT (NOT USED FOR MK 68)     C
C            16-20 IRAP  =0 CONVENTIONAL PROJECTILE                           C
C                        =1 ROCKET-ASSISTED PROJECTILE                        C
C            21-25 IKEEP NUMBER OF TERMS NOT TO BE DELETED IN RIVOR           C
C            26-30 KSTOP =1 READ IN NEW TYPE 1 CARD AFTER THIS RUN            C
C                        =2 STOP AFTER THIS RUN                               C
C                                                                             C
C     CARD TYPE 2 FORMAT(16I5)                                                C
C     COLS.   1- 5 ITERMS NUMBER OF TERMS TO BE USED IN FIRST FIT             C
C                                                                             C
C     CARD TYPE 3 FORMAT(16I5)   (FIVE CARDS)                                 C
C     COLS.   1- 5 II( 1) POSITION OF TERM IN FIT FUNCTION IF USED IN FIT     C
C             6-10 II( 2)    (OTHERWISE INPUT AS ZERO)                        C
C            11-15 II( 3)                                                     C
C              .       .      THIS SAME POSITION WILL APPLY TO CORRESPONDING  C
C              .       .      COEFFICIENTS AND ADDITIONAL RESIDUAL SUM OF     C
C              .       .      SQUARES FOR EACH TERM.  (FOR DESCRIPTION OF     C
C            75-80 II(16)     TERMS, SEE SECTION OF PROGRAM CODING ENTITLED   C
C            ETC.             *** DEFINE TERMS FOR FIT AND EVALUATION ***)    C
C                                                                             C
C     CARD TYPE 4 FORMAT(16I5)                                                C
C     COLS.   1- 5 ID    =1 5-INCH 54-CALIBER MARK 41 FULL CHARGE             C
C                        =2 5-INCH 54-CALIBER MARK 41 REDUCED CHARGE          C
C                        =3 5-INCH 54-CALIBER ROCKET-ASSISTED                 C
C                        =4 3-INCH 50-CALIBER MARK 33                         C
C                                                                             C
C     CARD TYPE 5 FORMAT(F7.5,3F7.4,F8.5,F7.4,F7.5,3F6.3,F7.4,F5.3)           C
C     COLS.    1- 7 FK     EFFECTIVE DRAG (*1000)                             C
C              8-14 FN     RATIO OF TANS OF ANGLE OF FALL AND ELEVATION ANGLE C
C             15-21 DRIFT  DRIFT (FEET*.0001)                                 C
C             22-28 X      SLANT RANGE (FEET*.0001)                           C
C             29-36 TF     TIME OF FLIGHT (SECONDS*.01)                       C
C             37-43 THES   SUPER-ELEVATION ANGLE (RADIANS)                    C
C             44-50 VOS    INITIAL VELOCITY (FEET/SECOND*.0001)               C
C             51-56 DENSE  BALLISTIC DENSITY (PER CENT OF STANDARD *.01)      C
C             57-62 TKS    BALLISTIC TEMPERATURE (DEGREES FAR. *.01)          C
C             63-68 WXS    BALLISTIC RANGE WIND (KNOTS *.01)                  C
C             69-75 PA     POSITION ANGLE (RADIANS)                           C
C             76-80 MTS    MOTOR TEMPERATURE (DEGREES FAR. *.01) (RAP ONLY)   C
C                                                                             C
C*****************************************************************************C
```

```
      COMMON A(76, 76), B(76, 1), BK(76, 1), IERR
      COMMON / IIII /  I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,
     1          I15,I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27,I28,
     2          I29,I30,I31,I32,I33,I34,I35,I36,I37,I38,I39,I40,I41,I42,
     3          I43,I44,I45,I46,I47,I48,I49,I50,I51,I52,I53,I54,I55,I56,
     4          I57,I58,I59,I60,I61,I62,I63,I64,I65,I66,I67,I68,I69,I70,
     5          I71,I72,I73,I74,I75,I76
      DIMENSION FK(1),X(1),VOS(1),THEO(1),DENSF(1),TKS(1),WXS(1),PA(1),
     1          WTK(1),DX(1),AF(1),DEGDX(4,75),ELANG(4,75),ANFAL(4,75),
     2          DUMMY(2),RMS(16),TF(1),ID1(16)
      DIMENSION II(76), Y(76), ARS(76), MT(1)
      EQUIVALENCE (Y(1) , DUMMY(2))
      EQUIVALENCE (II(76), I76)
      REAL MT, MS
      DATA G/32.174/
      DATA PI/3.14159265/, PI2/1.57079632/, PI4/.78539816/
C
C        ELEVATION ANGLE, DERIVATIVE OF ELEVATION ANGLE WITH          ****
C   **** RESPECT TO RANGE, AND ANGLE OF FALL
C        5-INCH 54-CALIBER MK-41 FULL CHARGE (OP 1182)
C
      DATA (ELANG(1,I), I = 1, 51)
     1     /.0080, .0123, .0167, .0214, .0262, .0312, .0365, .0421,
     2      .0479, .0539, .0603, .0670, .0740, .0814, .0891, .0973,
     3      .1059, .1151, .1247, .1349, .1456, .1579, .1690, .1817,
     4      .1951, .2092, .2241, .2399, .2557, .2725, .2900, .3084,
     5      .3276, .3892, .3677, .3892, .4116, .4352, .4599, .4861,
     6      .5137, .5437, .5763, .6120, .6551, .7098, .8212, .8212,
     7      .9251, .9719, 1.2217/
      DATA (DEGDX(1,I), I = 1, 51)
     1     /2.88, 3.00, 3.14, 3.25, 3.41, 3.56, 3.7, 3.9, 4.0, 4.3, 4.5,
     2      4.7, 5.0, 5.2, 5.5, 5.8, 6.2, 6.4, 6.9, 7.2, 7.7, 8.1, 8.5,
     3      9.0, 9.5, 10.0, 10.4, 11.0, 11.4, 12.0, 13.0, 13.0, 13.0,
     4      14.0, 15.0, 15.0, 16.0, 17.0, 17.0, 18.0, 20.0, 21.0, 23.0,
     5      27.0, 33.0, 49.0, 999.99, -999.99, -42.0, -28.0,  -9.4/
      DATA (ANFAL (1,I), I = 1, 51)
     1     /.0094, .0131, .0180, .0236, .0297, .0361, .0431, .0509,
     2      .0591, .0681, .0780, .0887, .1004, .1129, .1268, .1417,
     3      .1580, .1757, .1949, .2158, .2382, .2627, .2886, .3156,
     4      .3436, .3723, .4012, .4302, .4593, .4878, .5166, .5454,
     5      .5739, .6025, .6310, .6598, .6883, .7171, .7462, .7758,
     6      .8054, .8378, .8710, .9064, .9463, .9456, 1.0839,
     7      1.0839, 1.1566, 1.1869, 1.3413/
C
C        ELEVATION ANGLE, DERIVATIVE OF ELEVATION ANGLE WITH          ****
C   **** RESPECT TO RANGE, AND ANGLE OF FALL
C        5-INCH 54-CALIBER MK-41 REDUCED CHARGE (OP 3495)
C
      DATA (ELANG(2,I), I = 1, 36)
     1     / .0227, .0349, .0480, .0613, .0766, .0923, .1090, .1267,
     2      .1454, .1650, .1854, .2067, .2288, .2518, .2757, .3005,
     3      .3260, .3538, .3925, .4133, .4447, .4812, .5206, .5685,
     4      .6313, .7725, .7726, .9122, .9728, 1.0191, 1.0582, 1.0928,
     5      1.1242, 1.1533, 1.1800, 1.2064/
      DATA (DEGDX(2,I), I = 1, 36)
```

```
     1     /8.25, 8.75, 9.29, 9.89, 10.52, 11.20, 11.92, 12.69, 13.27,
     2     13.62, 14.39, 14.92, 15.54, 16.18, 16.82, 17.58, 18.38,
     3     19.32, 20.44, 21.81, 23.55, 25.69, 30.11, 37.58, 54.77,999.9,
     4     -999.99, -53.66, -34.38, -29.42, -25.43, -22.77, -20.90,
     5     -19.46, -18.29, -17.40/
      DATA (ANFAL(2,I), I = 1, 36)
     1     /.0239, .0379, .0535, .0713, .0914, .1129, .1356, .1604,
     2      .1858, .2122, .2391, .2666, .2949, .3240, .3539, .3846,
     3      .4162, .4490, .4830, .5186, .5561, .5963, .6395, .6914,.7565
     4     ,.8564, .8964, 1.0233, 1.0758, 1.1151, 1.1477, 1.1753,
     5     1.2023, 1.2264, 1.2484, 1.2693/
C
C         ELEVATION ANGLE, DERIVATIVE OF ELEVATION ANGLE WITH
C    **** RESPECT TO RANGE, AND ANGLE OF FALL                        ****
C         5-INCH 54-CALIBER ROCKET-ASSISTED
C
      DATA (ELANG(3,I), I = 1, 70)
     1     /.0075, .0114, .0156, .0200, .0245, .0204, .0344, .0397,
     2      .0453, .0512, .0574, .0640, .0709, .0783, .0861, .0946,
     3      .1032, .1125, .1225, .1331, .1444, .1564, .1693, .1827,
     4      .1951, .2091, .2219, .2344, .2469, .2594, .2717, .2842,
     5      .2969, .3098, .3229, .3364, .3501, .3643, .3789, .3938,
     6      .4092, .4250, .4412, .4578, .4749, .4924, .5104, .5289,
     7      .5479, .5675, .5878, .6088, .6306, .6533, .6773, .7025,
     8      .7295, .7588, .7911, .8281, .8726, .9341, 1.0552, 1.0552,
     9     1.1248, 1.1528, 1.1730, 1.1896, 1.2041, 1.2170/
      DATA (DEGDX(3,I), I = 1, 70)
     1     /2.69, 2.81, 2.95, 3.09, 3.24, 3.40, 3.58, 3.77, 3.97, 4.19,
     2      4.42, 4.67, 4.94, 5.24, 5.56, 5.90, 6.27, 6.67, 7.10, 7.57,
     3      8.07, 8.59, 9.12, 9.30, 9.07, 8.84, 8.70, 8.59, 8.53, 8.52,
     4      8.58, 8.66, 8.79, 8.94, 9.14, 9.38, 9.63, 9.92, 10.17,
     5      10.46, 10.73, 11.02, 11.30, 11.60, 11.91, 12.23, 12.57,
     6      12.93, 13.32, 13.75, 14.22, 14.78, 15.36, 16.10, 16.98,
     7      18.03, 19.42, 21.26, 23.87, 28.20, 35.18, 57.97, 999.99,
     8      -999.99, -26.28, -16.28, -12.65, -10.70, -9.45, -8.54/
      DATA (ANFAL(3,I), I = 1, 70)
     1     /.0079, .0122, .0171, .0223, .0281, .0344, .0414, .0489,
     2      .0572, .0665, .0764, .0874, .0995, .1129, .1277, .1438,
     3      .1616, .1811, .2024, .2253, .2513, .2787, .3071, .3275,
     4      .3322, .3363, .3420, .3497, .3589, .3703, .3834, .3984,
     5      .4155, .4347, .4556, .4787, .5031, .5285, .5544, .5804,
     6      .6066, .6327, .6587, .6847, .7107, .7364, .7622, .7879,
     7      .8133, .8392, .8650, .8910, .9173, .9439, .9711, .9990,
     8     1.0278, 1.0576, 1.0894, 1.1233, 1.1503, 1.2016, 1.2519,1.2519
     9     ,1.2721, 1.2822, 1.2903, 1.2976, 1.3042, 1.3107/
C
C         ELEVATION ANGLE, DERIVATIVE OF ELEVATION ANGLE WITH
C    **** RESPECT TO RANGE, AND ANGLE OF FALL                        ****
C         3-INCH 50-CALIBER MK-33 (OP 3795)
C
      DATA (ELANG(-,I), I = 1, 39)
     1     /.0075, .0113, .0157, .0221, .0282, .0355, .0428, .0516,
     2      .0618, .0735, .0867, .1015, .1179, .1359, .1556, .1769,
     3      .2001, .2252, .2525, .2822, .3146, .3502, .3099, .4348,
     4      .4873, .5531, .6557, .7445, .7443, .8308, .9248, .9831,
```

```
 5      1.0288, 1.0677, 1.1029, 1.1331, 1.1618, 1.1885, 1.2137/
  DATA (DEGDX(4,I), I = 1, 39)
 1     /2.87, 3.18, 3.54, 3.97, 4.47, 5.06, 5.73, 6.62, 7.59, 8.67,
 2      9.76, 10.84, 11.93, 13.05, 14.21, 15.42, 16.73, 18.12,
 3      19.76, 21.47, 23.54, 26.04, 29.29, 33.72, 40.56, 54.64,
 4      140.65, 999.99, -999.99, -134.64, -49.13, -35.02, -29.21,
 5      -25.28, -22.60, -20.64, -19.14, -17.91, -16.91/
  DATA (ANFAL (4,I), I = 1, 39)
 1     /.0082, .0138, .0204, .0284, .0386, .0510, .0661, .0852,
 2      .1085, .1363, .1672, .2009, .2670, .2757, .3171, .3612,
 3      .4082, .4575, .5095, .5636, .6202, .6785, .7392, .8024,
 4      .8692, .9430, 1.0402, 1.1102, 1.1590,1.1690, 1.2264, 1.2592,
 5      1.2840, 1.3044, 1.3222, 1.3382, 1.3529, 1.3665, 1.3794/
C
C    **** SET DISC CONTROLS AND START COUNTERS                    ****
C
      XXX = SECOND(TTT)
      L = 1
    1 LBACK = 1
      WTS = 1.
      KTAPE = 2
      LTAPE = 3
C
C    **** READ MAIN CONTROL CARD                                  ****
C
      READ 20, KSETS, INT, ITYPE, IRAP, IKEEP, KSTOP
      PRINT 10, INT, ITYPE
      PRINT 30
      IK1 = IKEEP + 1
      IK2 = IKEEP + 2
C
C    **** READ CARD IDENTIFYING TERMS TO BE USED IN FIT           ****
C
    2 READ 20, ITERMS
      READ 20, II
      ITKEEP = ITERMS
      CALL MOVE (0., ABS, ITERMS)
      DO 51  KK = 1, KSETS
C
C    **** READ DATA IDENTIFICATION CARD                           ****
C
      READ 20, ID
      ID1(KK) = ID
      COUNT = 0.
C
C    **** SET MATRIX ELEMENTS TO ZERO                             ****
C
   24 DO 25 I = 1,ITERMS
   25 CALL MOVE(0.,A(1,I), ITERMS)
      CALL MOVE (0., B, ITERMS)
      C = 0.
C
C    **** READ POINTS USED IN FITS (ONE POINT PER CARD)           ****
C
C    **** (X(L) EQUAL TO ZERO IDENTIFIES LAST DATA CARD FOR THIS SET) ***
```

```
C
  255 IF (IRAP .GT. 0) GO TO 26
      GO TO (31, 325, 325, 32, 326) ITYPE
C
C   **** EFFECTIVE DRAG FIT (ITYPE = 1)                                   ****
C
   31 READ 310,FK(L),X(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L)
      IF (X(L)) 4, 4, 301
C
C   **** RATIO FIT (ITYPE = 4)                                             ****
C
   32 READ 320,FK(L),X(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L)
      IF (X(L)) 4, 4, 301
C
C   **** DRIFT OR DELT FIT (ITYPE = 2 OR 3)                                ****
C
  325 READ 330,FK(L),X(L),TF(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),
     1          PA(L)
C
C   **** (IF DRIFT IS BEING FIT, WXS IS NOT USED AND IS SET TO TF)   ****
C
      IF ( ITYPE .EQ. 3) WXS(L) = TF(L)
      IF (X(L)) 4, 4, 301
C
C   **** TIME OF FLIGHT FIT (ITYPE = 5)                                    ****
C
  326 READ 340, X(L),FK(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L)
      IF (X(L)) 4, 4, 301
   26 GO TO (27, 29, 29, 28, 295) ITYPE
   27 READ 310,FK(L),X(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L),
     1          MT(L)
      IF (X(L)) 4, 4, 301
   28 READ 320,FK(L),X(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L),
     1          MT(L)
      IF (X(L)) 4, 4, 301
   29 READ 330,FK(L),X(L),TF(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),
     1          PA(L),MT(L)
      IF ( ITYPE .EQ. 3) WXS(L) = TF(L)
      IF (X(L)) 4, 4, 301
  295 READ 340,X(L),FK(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),PA(L),
     1          MT(L)
      IF (X(L)) 4, 4, 301
  301 XS = X(L)*X(L)
      MS = MT(L)*MT(L)
      VS = VOS(L)*VOS(L)
      DS = DENSE(L)*DENSE(L)
      TS = TKS(L)*TKS(L)
      WS = WXS(L)*WXS(L)
      PS = PA(L)*PA(L)
      XV = X(L)*VOS(L)
      XD = X(L)*DENSE(L)
      XW = X(L)*WXS(L)
      VD = VOS(L)*DENSE(L)
      DW = DENSE(L)*WXS(L)
C
```

```
C     **** DEFINE TERMS USED FOR FIT AND EVALUATION                    ****
C
      Y(I 1) = 1.
      Y(I 2) = X(L)
      Y(I 3) = VOS(L)
      Y(I 4) = DENSE(L)
      Y(I 5) = TKS(L)
      Y(I 6) = WXS(L)
      Y(I 7) = PA(L)
      Y(I 8) = XV
      Y(I 9) = XD
      Y(I10) = X(L)*TKS(L)
      Y(I11) = XW
      Y(I12) = X(L)*PA(L)
      Y(I13) = VD
      Y(I14) = VOS(L)*TKS(L)
      Y(I15) = VOS(L)*WXS(L)
      Y(I16) = VOS(L)*PA(L)
      Y(I17) = DENSE(L)*TKS(L)
      Y(I18) = DW
      Y(I19) = DENSE(L)*PA(L)
      Y(I20) = TKS(L)*WXS(L)
      Y(I21) = TKS(L)*PA(L)
      Y(I22) = WXS(L)*PA(L)
      Y(I23) = XS
      Y(I24) = PS
      Y(I25) = X(L)*DS
      Y(I26) = X(L)*WS
      Y(I27) = X(L)*PS
      Y(I28) = VOS(L)*XS
      Y(I29) = VOS(L)*DS
      Y(I30) = VOS(L)*WS
      Y(I31) = VOS(L)*PS
      Y(I32) = DENSE(L)*XS
      Y(I33) = DENSE(L)*WS
      Y(I34) = DENSE(L)*PS
      Y(I35) = PA(L)*XS
      Y(I36) = PA(L)*VS
      Y(I37) = PA(L)*DS
      Y(I38) = PA(L)*TS
      Y(I39) = PA(L)*WS
      Y(I40) = X(L)*XS
      Y(I41) = PA(L)*PS
      Y(I42) = XV*DENSE(L)
      Y(I43) = XV*WXS(L)
      Y(I44) = XV*PA(L)
      Y(I45) = XD*WXS(L)
      Y(I46) = XD*PA(L)
      Y(I47) = XW*PA(L)
      Y(I48) = VD*WXS(L)
      Y(I49) = VD*PA(L)
      Y(I50) = DW*TKS(L)
      Y(I51) = WS
      Y(I52)=VS
      Y(I53)=DS
```

```
      IF (TRAP) 313, 313, 312
  312 Y(I52) = MT(L)
      Y(I53) = MT(L)*X(L)
      Y(I54) = MT(L)*VOS(L)
      Y(I55) = MT(L)*DENSE(L)
      Y(I56) = MT(L)*TKS(L)
      Y(I57) = MT(L)*PA(L)
      Y(I58) = MS
      Y(I59) = MS*X(L)
      Y(I60) = MS*VOS(L)
      Y(I61) = MS*DENSE(L)
      Y(I62) = MS*TKS(L)
      Y(I63) = MS*PA(L)
      Y(I64) = MT(L)*XS
      Y(I65) = MT(L)*VS
      Y(I66) = MT(L)*DS
      Y(I67) = MT(L)*TS
      Y(I68) = MT(L)*PS
      Y(I69) = MT(L)*X(L)*PA(L)
      Y(I70) = MT(L)*X(L)*VOS(L)
      Y(I71) = MT(L)*PA(L)*VOS(L)
  313 COUNT = COUNT + 1.
      GO TO (314, 351, 355, 355, 355) ITYPE
  314 GO TO (355, 315, 315) IWT
C
C  **** INTERPOLATE FOR ANGLE OF FALL AND DERIVATIVE (COLUMN 28)    ****
C
  315 DO 331 I = 2 , 100
      IF (THED(L) - ELANG(ID,I)) 332, 332, 331
  331 CONTINUE
      PRINT 3310
      GO TO 9997
  332 IF (ELANG(ID,I) .GT. 2.) I = I - 1
      IM1 = I - 1
      RATIO = (THED(L) - ELANG(ID,IM1))/(ELANG(ID,I) - ELANG(ID,IM1))
      AF(L) = ANFAL(ID,IM1) + RATIO*(ANFAL(ID,I) - ANFAL(ID,IM1))
      DX(L) = DEGDX(ID,IM1) + RATIO*(DEGDX(ID,I) - DEGDX(ID,IM1))
C
C  **** COMPUTE HEIGHT FOR EACH DATA POINT                          ****
C
  311 GO TO (355,33, 34) IWT
   33 HTK(L) = (110.614*X(L)*(1.+FK(L)*X(L)))/(VS*COS(2.*THED(L))*DX(L))
     1          *COS(PA(L)))
      GO TO 35
   34 HTK(L) = (110.614*X(L)*(1.+FK(L)*X(L)))/(VS*COS(2.*THED(L))*DX(L))
     1         *TAN(AF(L))*X(L)     *COS(PA(L))**.333333333
   35 HTS = HTK(L)*HTK(L)
      GO TO 355
C
C  **** COMPUTE DELT (ITYPE = 2)                                    ****
C
  351 XH = X(L)*COS(PA(L))
      XV = X(L)*SIN(PA(L))
      PAT = PA(L) + THED(L)
      DX = XH / (VOS(L)*COS(PAT))
```

```
      TTC = SQRT((60000.*AX*VOS(L)*SIN(PAT) -60000.*XV -G*AX*AX)/64.348)
      FK(L) = TTC - TF(L)*100.
C                                                                  ****
C  **** INCREMENT NORMAL MATRIX
C
  355 DO 37 I = 1, ITERMS
      DO 36 J = 1, ITERMS
   36 A(I,J) = A(I,J) + Y(I)*Y(J)*WTS
   37 B(I,1) = B(I,1) + Y(I)*FK(L)*WTS
      C = C + FK(L)*FK(L)*WTS
      GO TO 255
C                                                                  ****
C  **** STORE MATRIX DATA ON DISK FOR LATER USE
C
    4 WRITE(KTAPE)  ((A(I,J), I = 1, ITERMS), J= 1, ITERMS),
     1              (B(I,1), I = 1, ITERMS), C, COUNT
      DO 401 I = 1, ITERMS
  401 BK(I, 1) = B(I, 1)
C                                                                  ****
C  **** INVERT NORMAL MATRIX AND COMPUTE RMS AND ARS
C
  411 CALL DPINVR(ITERMS)
      IF (IERR) 9999, 42, 9999
   42 SS= C
      DO 43 I = 1, ITERMS
      ARS(I) = ARS(I) + B (I,1)*B (I,1)/A(I,I)
   43 SS = SS -BK(I,1)*B(I,1)
      IF (SS .LT. 0.) SS = .0000001
      RMS(KK) = SQRT(SS/COUNT)
C                                                                  ****
C  **** PRINT GENERATED COEFFICIENTS
C
      PRINT 80
      PRINT 500, (I, B (I,1), I = 1, ITERMS)
      GO TO (51, 7) LBACK
   51 CONTINUE
      LBACK = 2
C                                                                  ****
C  **** FIND TERM WITH MINIMUM VALUE OF ARS
C
  511 ARMIN = ARS(IK1)
      IMIN = IK1
      DO 52 I = IK2, ITERMS
      IF (ARS(I) - ARMIN) 515, 52, 52
  515 ARMIN = ARS(I)
      IMIN = I
   52 CONTINUE
      IMP1 = IMIN+ 1
      IMM1 = IMIN - 1
C                                                                  ****
C  **** PRINT TERMS USED IN FIT
C
      PRINT 410
      PRINT 430, ITERMS,II
C
```

```
C     **** PRINT RMS FOR EACH SET OF DATA                              ****
C
         PRINT 520, (KK, RMS(KK),ID1(KK), KK = 1, KSETS)
         PRINT 510
C
C     **** PRINT ADDITIONAL RESIDUAL SUM OF SQUARES FOR EACH TERM      ****
C
         PRINT 530,(I, ARS(I), I = 1, ITERMS)
         DO 6 I = 1, 76
         IF (II(I)) 6, 6, 55
      55 IF (II(I) - IMIN) 6, 56, 57
      56 II(I) = 0
         GO TO 6
      57 II(I) = II(I) - 1
       6 CONTINUE
         ITP1 = ITERMS
         ITERMS = ITERMS - 1
         REWIND KTAPE
         REWIND LTAPE
         IF (ITERMS .LT. IKEEP ) GO TO 3397
         PRINT 30
C
C        **** CONSTRUCT NORMAL MATRIX WITH ONE LESS ROW AND COLUMN     ****
C
         KLSAVE = KTAPE
         KTAPE = LTAPE
         LTAPE = KLSAVE
         DO 61 I = 1, ITERMS
      61 ARS(I) = 0.0
         KK = 1
      62 READ (LTAPE) ((A(I,J), I = 1, ITP1  ), J= 1, ITP1  ),
        1               (B(I,1), I = 1, ITP1  ), C, COUNT
         IF (IMIN .GT. ITERMS) GO TO 4
         IF ( IMM1 .EQ. 0) GO TO 645
         DO 64 I = 1, IMM1
         IP1  = I + 1
         DO 64 J = IMIN, ITERMS
         JP1 = J + 1
      64 A(I, J) = A (I, JP1)
     645 DO 67 I = IMIN, ITERMS
         IP1 = I + 1
         IF (IMM1 .EQ. 0) GO TO 655
         DO 65 J = 1, IMM1
         JP1  = J + 1
      65 A(I, J) = A (IP1, J)
     655 DO 66 J = IMIN, ITERMS
         JP1 = J + 1
      66 A(I,J) = A (IP1, JP1)
      67 B(I,1) = B (IP1,1)
         GO TO 4
       7 KK = KK + 1
         IF(KK - KSETS) 62, 62, 511
C
C     **** PRINT RUNNING TIME                                          ****
C
```

```
 9997 YYY = SECOND(TTT)
      GAP = YYY - XXX
      PRINT 1100, GAP
C
C   **** MONITOR KSTOP                                                ****
C
      GO TO (1, 9998) KSTOP
 9999 PRINT 900, IERR
 9998 STOP
   10 FORMAT (1H1, 59X, 15HSELECT PROCEDURE//57X, 6HINT = , I1, 4X,
     1          8HITYPE = , I1)
   20 FORMAT (16I5)
   30 FORMAT (1H1, 59X, 12HCOEFFICIENTS)
   50 FORMAT (1H1)
   70 FORMAT (1HL)
   80 FORMAT (1HL)
  220 FORMAT (5E14.7)
  310 FORMAT (F7.5,14X,F7.4,8X,  F7.4,F7.5,3F6.3,F7.4,F5.3)
  320 FORMAT (7X,F7.3,7X,F7.4,3X,F7.4,F7.5,3F5.3,F7.4,F5.3)
  330 FORMAT (14X,2F7.4,F8.4,     F7.4,F7.5,3F5.3,F7.4,F5.3)
  340 FORMAT (21X,F7.4,F8.4,      F7.4,F7.5,3F6.3,F7.4,F5.3)
  410 FORMAT (1H-, 10X, 6HNUMBER, 22X, 10HTERMS USED, 23X,
     1          53HRMS VALUES FOR EACH DATA SET WITH IDENTIFICATION (ID)/
     2          11X, 8HOF TERMS, 20X, 6HIN FIT, 30X,
     3          47H(SEE INPUT GUIDE FOR EXPLANATION OF ID MEANING)/)
  430 FORMAT (14X,I2,3X,14(1X,I2)/19X,14(1X,I2)/19X,14(1X,I2)/
     1           19X,14(1X,I2)/19X,14(1X,I2)/19X,14(1X,I2))
  500 FORMAT (7(I4, F14.7))
  510 FORMAT (1H-, 41X, 44HADDITIONAL RESIDUAL SUM OF SQUARES FOR EACH ,
     1           4HTERM)
  520 FORMAT(6(X,I3,F12.7,I2,I3,F12.7,I2,I3,F12.7,I2,I3,F12.7,I2)
  530 FORMAT (8(I4, E12.5))
  900 FORMAT(30H MATRIX WILL NOT INVERT-IERR =, I5)
 1100 FORMAT (/50X,17HEXECUTION TIME = , F8.3, 8H SECONDS)
 3310 FORMAT (19H CHECK DIGDX TABLES)
      END
```

```
      SUBROUTINE DPINVB(NNN)
      COMMON A(76, 76), B(76, 1), BK(76, 1), IERR
      DIMENSION INDEX(76,2), IPIVOT(76)                                 GAUSS120
C                                                                       GAUSS130
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)         GAUSS140
C                                                                       GAUSS150
C     INITIALIZATION                                                    GAUSS160
C
      M = 1
      N = NNN
   10 DETERM=1.0                                                        GAUSS190
   15 DO 20 J=1,N                                                       GAUSS200
   20 IPIVOT(J)=0                                                       GAUSS210
   30 DO 550 I=1,N                                                      GAUSS220
C                                                                       GAUSS240
C     SEARCH FOR PIVOT ELEMENT                                          GAUSS250
C                                                                       GAUSS260
   40 AMAX=0.0                                                          GAUSS270
   45 DO 105 J=1,N                                                      GAUSS280
   50 IF (IPIVOT(J)-1) 60, 105, 60                                      GAUSS290
   60 DO 100 K=1,N                                                      GAUSS300
   70 IF (IPIVOT(K)-1) 80,100,699                                       GAUSS310
   80 IF (ABS(AMAX)-ABS(A(J,K))) 85, 100, 100                           GAUSS320
   85 IROW=J                                                            GAUSS330
   90 ICOLUM=K                                                          GAUSS340
   95 AMAX=A(J,K)                                                       GAUSS350
  100 CONTINUE                                                          GAUSS370
  105 CONTINUE                                                          GAUSS380
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1                                   GAUSS420
      IF (A(ICOLUM,ICOLUM)) 130,899,130                                 GAUSS430
C                                                                       GAUSS440
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL                 GAUSS450
C                                                                       GAUSS460
  130 IF (IROW-ICOLUM) 140, 260, 140                                    GAUSS470
  140 DETERM=-DETERM                                                    GAUSS480
  150 DO 200 L=1,N                                                      GAUSS490
  160 SWAP=A(IROW,L)                                                    GAUSS500
  170 A(IROW,L)=A(ICOLUM,L)                                             GAUSS510
  200 A(ICOLUM,L)=SWAP                                                  GAUSS520
  210 DO 250 L=1, M                                                     GAUSS530
  220 SWAP=B(IROW,L)                                                    GAUSS540
  230 B(IROW,L)=B(ICOLUM,L)                                             GAUSS550
  250 B(ICOLUM,L)=SWAP                                                  GAUSS560
  260 INDEX(I,1)=IROW                                                   GAUSS570
  270 INDEX(I,2)=ICOLUM                                                 GAUSS580
  310 PIVOT    =A(ICOLUM,ICOLUM)                                        GAUSS590
  320 DETERM=DETERM*PIVOT                                               GAUSS600
C                                                                       GAUSS610
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT                                 GAUSS620
C                                                                       GAUSS630
  330 A(ICOLUM,ICOLUM)=1.0                                              GAUSS640
  340 DO 350 L=1,N                                                      GAUSS650
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT                                     GAUSS660
  360 DO 370 L=1,M                                                      GAUSS670
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT                                     GAUSS680
```

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SUBROUTINE  OPTIMP                          CDC 6600 FTN V3.0-P308 OPT=1  07/26/72  16.54.52.      PAGE    2

                                                                                GAUSS690
      C                                                                         GAUSS700
      C     REDUCE NON-PIVOT ROWS                                               GAUSS710
      C                                                                         GAUSS720
        380 DO 550 L1=1,N                                                       GAUSS730
        390 IF(L1-ICOLUM) 400, 550, 400                                         GAUSS740
        400 T=A(L1,ICOLUM)                                                      GAUSS750
        420 A(L1,ICOLUM)=0.0                                                    GAUSS760
        430 DO 450 L=1,N                                                        GAUSS770
        450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T                                       GAUSS780
        460 DO 500 L=1,M                                                        GAUSS790
        500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T                                       GAUSS800
        550 CONTINUE                                                            GAUSS810
      C                                                                         GAUSS820
      C     INTERCHANGE COLUMNS                                                 GAUSS830
      C                                                                         GAUSS840
        600 DO 710 I=1,N                                                        GAUSS850
        610 L=N+1-I                                                             GAUSS860
        620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630                            GAUSS870
        630 JROW=INDEX(L,1)                                                     GAUSS880
        640 JCOLUM=INDEX(L,2)                                                   GAUSS890
        650 DO 705 K=1,M                                                        GAUSS900
        660 SWAP=A(K,JROW)                                                      GAUSS910
        670 A(K,JROW)=A(K,JCOLUM)                                               GAUSS920
        700 A(K,JCOLUM)=SWAP                                                    GAUSS930
        705 CONTINUE                                                            GAUSS940
        710 CONTINUE
            IERR = 0                                                            GAUSS950
        740 RETURN
        899 IERR = 1                                                            GAUSS970
            RETURN                                                              GAUSS980
            END
```

APPENDIX G

COMPUTER LISTING FOR "RANDOM" PROGRAM

```
      PROGRAM RANDOM(INPUT, OUTPUT)
      DIMENSION DEGDX(4, 75), ELANG(4, 75), A(25,25), B(25,1), ACUME(15)
     1        , RESULT(15), IDEN(15),Y(60), BK(25,1), DUMMY(2), ITYP(2),
     2          FK(2000), X(2000), TF(2000), THED(2000), VOS(2000),
     3          DENSE(2000), TKS(2000), HXS(2000), PA(2000), HTK(2000),
     4          THEDG(2000), MT(2000), DX(2000) ,TC(2000)
      DIMENSION ANFAL(4, 75), AF(2000), AK(25,25), AL(25,25), BL(25,1)
      COMMON / IIII /  I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,
     1        I15,I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27,I28,
     2        I29,I30,I31,I32,I33,I34,I35,I36,I37,I38,I39,I40,I41,I42,
     3        I43,I44,I45,I46,I47,I48,I49,I50,I51
      COMMON / KKKK/   K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,
     1        K15,K16,K17,K18,K19,K20,K21,K22,K23,K24,K25,K26,K27,K28,
     2        K29,K30,K31,K32,K33,K34,K35,K36,K37,K38,K39,K40,K41,K42,
     3        K43,K44,K45,K46,K47,K48,K49,K50,K51
      REAL MD
      REAL MT, MT1
      EQUIVALENCE (Y(1) , DUMMY(2))
      DATA G/32.174/
      DATA PI/3.14159265/, PI2/1.57079632/, PI4/.78539816/
      DATA (ELANG(1,I), I = 1, 52)
     1     /.0080, .0123, .0167, .0214, .0262, .0312, .0365, .0421,
     2      .0479, .0539, .0603, .0670, .0740, .0814, .0891, .0973,
     3      .1059, .1151, .1247, .1349, .1456, .1579, .1690, .1817,
     4      .1951, .2092, .2241, .2395, .2557, .2726, .2900, .3084,
     5      .3276, .3892, .3677, .3892, .4116, .4352, .4599, .4861,
     6      .5137, .5437, .5763, .6126, .6551, .7098, .8212, .8212,
     7      .9251, .9719, 1.2217, 1.3000/
      DATA (DEGDX(1,I), I = 1, 52)
     1     /2.88, 3.00, 3.14, 3.26, 3.41, 3.55, 3.7, 3.9, 4.0, 4.3, 4.5,
     2     4.7, 5.0, 5.2, 5.5, 5.8, 6.2, 6.4, 6.9, 7.2, 7.7, 8.1, 8.5,
     3     9.0, 9.5, 10.0, 10.4, 11.0, 11.4, 12.0, 13.0, 13.0, 13.0,
     4     14.0, 15.0, 15.0, 16.0, 17.0, 17.0, 18.0, 20.0, 21.0, 23.0,
     5     27.0, 33.0, 49.0, 999.99, -999.99, -42.0, -28.0, -9.4, -5.0/
      DATA (ANFAL (1,I), I = 1, 52)
     1     /.0084, .0131, .0180, .0236, .0297, .0361, .0431, .0509,
     2      .0591, .0681, .0780, .0887, .1004, .1129, .1258, .1417,
     3      .1580, .1757, .1949, .2158, .2382, .2627, .2885, .3156,
     4      .3436, .3723, .4012, .4302, .4590, .4878, .5165, .5454,
     5      .5739, .6025, .6310, .6598, .6883, .7171, .7462, .7758,
     6      .8064, .8378, .8710, .9064, .9453, .9456, 1.0839,
     7      1.0839, 1.1566, 1.1869, 1.3413, 1.3900/
      DATA (ELANG(2,I), I = 1, 36)
     1    / .0227, .0349, .0480, .0618, .0766, .0923, .1090, .1267,
     2     .1454, .1650, .1854, .2067, .2288, .2518, .2757, .3005,
     3     .3265, .3538, .3825, .4130, .4457, .4812, .5206, .5685,
     4     .6308, .7726, .7726, .9122, .9728, 1.0191, 1.0582, 1.0928,
     5     1.1242, 1.1533, 1.1805, 1.2064/
      DATA (DEGDX(2,I), I = 1, 36)
     1     /8.26, 8.76, 9.29, 9.88, 10.52, 11.20, 11.92, 12.59, 13.23,
     2     13.82, 14.39, 14.92, 15.54, 16.18, 16.82, 17.58, 18.38,
     3     19.32, 20.44, 21.81, 23.55, 25.69, 30.11, 37.58, 54.73,999.9,
     4    -999.99, -53.66, -34.38, -29.42, -25.43, -22.77, -20.90,
     5     -19.46, -18.29, -17.40/
      DATA (ANFAL(2,I), I = 1, 36)
```

```
           1      /.0239, .0379, .0536, .0710, .0904, .1120, .1356, .1504,
           2       .1858, .2122, .2391, .2666, .2949, .3240, .3539, .3846,
           3       .4162, .4490, .4830, .5186, .5561, .5963, .6395, .6914,.7566
           +      ,.8964, .8964, 1.0233, 1.0758, 1.1151, 1.1477, 1.1763,
           5      1.2023, 1.2264, 1.2484, 1.2593/
          DATA (ELANG(3,I), I = 1, 70)
           1      /.0075, .0114, .0156, .0200, .0245, .0294, .0344, .0397,
           2       .0453, .0512, .0574, .0640, .0709, .0783, .0861, .0944,
           3       .1032, .1125, .1225, .1331, .1444, .1564, .1593, .1827,
           4       .1961, .2091, .2219, .2344, .2469, .2594, .2717, .2842,
           5       .2969, .3098, .3229, .3364, .3501, .3643, .3789, .3938,
           6       .4092, .4250, .4412, .4578, .4749, .4924, .5104, .5289,
           7       .5479, .5675, .5878, .6088, .6306, .6533, .6773, .7025,
           8       .7295, .7588, .7911, .8281, .8726, .9341, 1.0552, 1.0552,
           9      1.1248, 1.1528, 1.1730, 1.1896, 1.2041, 1.2170/
          DATA (DEGDX(3,I), I = 1, 70)
           1      /2.69, 2.81, 2.95, 3.09, 3.24, 3.40, 3.58, 3.77, 3.97, 4.19,
           2       4.42, 4.67, 4.94, 5.24, 5.56, 5.90, 6.27, 6.67, 7.10, 7.57,
           3       8.07, 8.59, 9.12, 9.30, 9.07, 8.84, 8.70, 8.59, 8.53, 8.52,
           4       8.58, 8.66, 8.79, 8.94, 9.14, 9.38, 9.63, 9.92, 10.17,
           5       10.46, 10.73, 11.02, 11.30, 11.60, 11.91, 12.23, 12.57,
           6       12.93, 13.32, 13.75, 14.22, 14.78, 15.36, 16.10, 16.98,
           7       18.03, 19.42, 21.26, 23.87, 28.20, 35.18, 57.97, 999.99,
           8       -999.99, -26.28, -16.28, -12.65, -10.70, -9.45, -8.54/
          DATA (ANFAL(3,I), I = 1, 70)
           1      /.0079, .0122, .0171, .0223, .0281, .0344, .0414, .0489,
           2       .0572, .0665, .0764, .0874, .0996, .1129, .1277, .1438,
           3       .1616, .1811, .2024, .2258, .2513, .2787, .3071, .3275,
           4       .3322, .3363, .3420, .3497, .3589, .3703, .3834, .3984,
           5       .4155, .4347, .4556, .4787, .5031, .5286, .5544, .5804,
           6       .6066, .6327, .6587, .6847, .7107, .7364, .7622, .7879,
           7       .8133, .8392, .8650, .8910, .9173, .9439, .9711, .9990,
           8      1.0278, 1.0576, 1.0894, 1.1233, 1.1603, 1.2016, 1.2519,1.2519
           9     ,1.2721, 1.2822, 1.2903, 1.2976, 1.3042, 1.3107/
          DATA (ELANG(4,I), I = 1, 39)
           1      /.0075, .0119, .0167, .0221, .0282, .0350, .0428, .0516,
           2       .0618, .0735, .0867, .1015, .1179, .1359, .1556, .1769,
           3       .2001, .2252, .2525, .2822, .3146, .3502, .3899, .4348,
           4       .4873, .5531, .6557, .7443, .7443, .8308, .9248, .9831,
           5       1.0288, 1.0677, 1.1020, 1.1331, 1.1618, 1.1885, 1.2137/
          DATA (DEGDX(4,I), I = 1, 39)
           1      /2.87, 3.18, 3.54, 3.97, 4.47, 5.06, 5.78, 6.62, 7.59, 8.67,
           2       9.76, 10.84, 11.93, 13.05, 14.21, 15.42, 16.73, 18.12,
           3       19.70, 21.47, 23.54, 26.04, 29.29, 33.72, 40.56, 54.64,
           4       140.65, 999.99, -999.99, -134.84, -49.15, -35.52, -29.21,
           5       -25.28, -22.60, -20.64, -19.14, -17.91, -15.91/
          DATA (ANFAL (4,I), I = 1, 39)
           1      /.0082, .0138, .0204, .0284, .0386, .0510, .0661, .0852,
           2       .1085, .1363, .1672, .2008, .2670, .2757, .3171, .3612,
           3       .4082, .4575, .5095, .5636, .5202, .6786, .7392, .8024,
           4       .8692, .9430, 1.0402, 1.1102, 1.1690,1.1690, 1.2264, 1.2592,
           5       1.2840, 1.3044, 1.3222, 1.3382, 1.3529, 1.3665, 1.3794/
          DATA (ITYP(I), I=1,2) /8HSURFACE , 8H    AA    /
          DATA (IDEN(I),I=1,16)
           1      /8H     5-I, 8HNCH 54 F, 8HJLL CHAR, 8HGE       ,
```

```
     2      8H 5-INCH , 8H54 REDUC, 8HED CHARG, 8HE       ,
     3      8H 5-INCH , 8H54 ROCKE, 8HT-ASSIST, 8HED      ,
     4      8H        , 8H   3 INC, 8H4 50   , 8H         /
C
C       ID = 1 5-INCH 54 FULL CHARGE     ITYPE = 1 SURFACE
C       ID = 2 5-INCH 54 REDUCED CHARGE  ITYPE = 2 AA
C       ID = 3 5-INCH 54 ROCKET ASSISTED
C       ID = 4 3-INCH 50
C
C      IFIT = 1 FIT FK ONLY          IWT = 1 MINIMIZE FK ERROR
C      IFIT = 2 FIT AND EVALUATE     IWT = 2 MINIMIZE MIL ERROR
C      IFIT = 3 EVALUATE ONLY        IWT = 3 MINIMIZE MISS DISTANCE
C      IFIT = 4 FIT FK AND DELT ITERATING ON DELT
C
C       IPRINT = 0 PRINT POINT-BY-POINT EVALUATION (IFIT= 2, 3, 4 )
C       IPRINT = 1 PRINT CUMULATIVE RESULTS ONLY
C   **** READ TERMS USED IN FK AND DELT FITS                          ****
C
    2 READ 10, ITERMS
      READ 20, I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,
     1         I15,I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27,I28,
     2         I29,I30,I31,I32,I33,I34,I35,I36,I37,I38,I39,I40,I41,I42,
     3         I43,I44,I45,I46,I47,I48,I49,I50,I51
   21 READ 10, KTERMS
      READ 20, K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,
     1         K15,K16,K17,K18,K19,K20,K21,K22,K23,K24,K25,K26,K27,K28,
     2         K29,K30,K31,K32,K33,K34,K35,K36,K37,K38,K39,K40,K41,K42,
     3         K43,K44,K45,K46,K47,K48,K49,K50,K51
C
C
C   **** READ MAIN CONTROL CARD                                       ****
C
    1 READ 10, ID, ITYPE, IFIT, IWT, IPRINT
C
      GO TO (22, 22, 215, 22) IFIT
  215 READ 220, (B(I,1), I = 1, ITERMS)
      READ 220,(BK(I,1), I = 1, KTERMS)
   22 IZ = 4*ID
      IY = IZ - 1
      IX = IY - 1
      IW = IX - 1
      PRINT 200,IDEN(IW),IDEN(IX),IDEN(IY),IDEN(IZ), ITYP(ITYPE)
      DO 101 I = 1, 15
  101 ACUME(I) = 0.0
      L = 0
      JGO = 1
      GO TO (24, 24, 26, 24) IFIT
   24 DO 25 I = 1,ITERMS
      B(I,1) = 0.
      DO 25 J = 1, ITERMS
   25 A(I,J) = 0.0
      C = 0.
      LBACK = 1
      GO TO 27
   26 PRINT 710
```

```
      LBACK = 2
   27 JBACK = LBACK
C
C     **** READ POINTS USED IN FITS (ONE POINT PER CARD)               ****
C
    3 L = L + 1
      READ 30, FK(L),X(L),TF(L),THEO(L),VOS(L),DENSE(L),TKS(L),WXS(L),
     1         PA(L),MT(L)
      IF (FK(L)) 4, 4, 301
  301 XS = X(L)*X(L)
      VS = VOS(L)*VOS(L)
      DS = DENSE(L)*DENSE(L)
      TS = TKS(L)*TKS(L)
      WS = WXS(L)*WXS(L)
      PS = PA(L)*PA(L)
      XV = X(L)*VOS(L)
      XD = X(L)*DENSE(L)
      VD = VOS(L)*DENSE(L)
      XW = X(L)*WXS(L)
C
C     **** DEFINE TERMS FOR FK FIT AND EVALUATION                      ****
C
      Y(I 1) = 1.
      Y(I 2) = X(L)
      Y(I 3) = VOS(L)
      Y(I 4) = DENSE(L)
      Y(I 5) = TKS(L)
      Y(I 6) = WXS(L)
      Y(I 7) = PA(L)
      Y(I 8) = X(L)*VOS(L)
      Y(I 9) = X(L)*DENSE(L)
      Y(I10) = X(L)*TKS(L)
      Y(I11) = X(L)*WXS(L)
      Y(I12) = X(L)*PA(L)
      Y(I13) = VOS(L)*DENSE(L)
      Y(I14) = VOS(L)*TKS(L)
      Y(I15) = VOS(L)*WXS(L)
      Y(I16) = VOS(L)*PA(L)
      Y(I17) = DENSE(L)*TKS(L)
      Y(I18) = DENSE(L)*WXS(L)
      Y(I19) = DENSE(L)*PA(L)
      Y(I20) = TKS(L)*WXS(L)
      Y(I21) = TKS(L)*PA(L)
      Y(I22) = WXS(L)*PA(L)
      Y(I23) = XS
      Y(I24) = PS
      Y(I25) = X(L)*DS
      Y(I26) = X(L)*WS
      Y(I27) = X(L)*PS
      Y(I28) = VOS(L)*XS
      Y(I29) = VOS(L)*DS
      Y(I30) = VOS(L)*WS
      Y(I31) = VOS(L)*PS
      Y(I32) = DENSE(L)*XS
      Y(I33) = DENSE(L)*WS
```

```
      Y(I34) = DENSE(L)*PS
      Y(I35) = PA(L)*XS
      Y(I36) = PA(L)*VS
      Y(I37) = PA(L)*DS
      Y(I38) = PA(L)*TS
      Y(I39) = PA(L)*WS
      Y(I40) = X(L)*XS
      Y(I41) = PA(L)*PS
      Y(I42) = XV*DENSE(L)
      Y(I43) = XV*WXS(L)
      Y(I44) = XV*PA(L)
      Y(I45) = XD*WXS(L)
      Y(I46) = XD*PA(L)
      Y(I47) = XW*PA(L)
      Y(I48) = VD*WXS(L)
      Y(I49) = VD*PA(L)
      Y(I50) = DENSE(L)*TKS(L)*WXS(L)
      Y(I51) = WS
   31 GO TO (315, 6) JGO
  315 DO 331 I = 2 , 100
      IF (THEO(L) - ELANG(ID,1)) 332, 332, 331
  331 CONTINUE
      PRINT 3310
      GO TO 9997
  332 IF (ELANG(ID,I) .GT. 2.) I = I - 1
      IM1 = I - 1
      RATIO = (THEO(L) - ELANG(ID,IM1))/(ELANG(ID,I) - ELANG(ID,IM1))
      AF(L) = ANFAL(ID,IM1) + RATIO*(ANFAL(ID,I) - ANFAL(ID,IM1))
      DX(L) = DEGDX(ID,IM1) + RATIO*(DEGDX(ID,I) - DEGDX(ID,IM1))
      GO TO (311, 6) LBACK
C
C **** COMPUTE HEIGHT FOR EACH DATA POINT                               ****
C
  311 GO TO (32, 33, 34) IWT
   32 WTK(L) = 1.
      GO TO 35
   33 WTK(L) = (110.614*X(L)*(1.+FK(L)*X(L)))/(VS*COS(2.*THEO(L))*DX(L))
     1          *COS(PA(L))
      GO TO 35
   34 WTK(L) = (110.614*X(L)*(1.+FK(L)*X(L)))/(VS*COS(2.*THEO(L))*DX(L))
     1          *TAN(AF(L))*X(L)      *COS(PA(L))*3.333333333
   35 WTS = WTK(L)*WTK(L)
      DO 37 I = 1, ITERMS
      DO 36 J = 1, ITERMS
   36 A(I,J) = A(I,J) + Y(I)*Y(J)*WTS
   37 B(I,1) = B(I,1) + Y(I)*FK(L)*WTS
      C = C + FK(L)*FK(L)*WTS
      GO TO 3
    4 NPOINT = L-1
      COUNT = NPOINT
      GO TO (401, 401, 895, 401) IFIT
  401 DO 41 I = 1, ITERMS
      DO 402 J = 1, ITERMS
  402 AK(I, J) = A(I,J)
   41 BK(I,1) = B(I,1)
```

```
C
C   **** INVERT NORMAL MATRIX FOR FK FUNCTION                          ****
C
  411 CALL MATNVR(A, ITERMS, B, 1, DETERM, IERR)
      IF (IERR) 9999, 42, 9999
   42 SS= C
      DO 43 I = 1, ITERMS
   43 SS = SS -BK(I,1)*B(I,1)
      RMS = SQRT(SS/COUNT)
      IF (JGO .EQ. 1) PRINT 410
      PRINT 420, RMS
      PRINT 430,      ITERMS,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,
     2           I14,I15,I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27
     3          ,I28,I29,I30,I31,I32,I33,I34,I35,I36,I37,I38,I39,I40,I41
     4          ,I42,I43,I44,I45,I46,I47,I48,I49,I50,I51
      PRINT 210, (B(I,1), I = 1, ITERMS)
      GO TO (44, 5, 5, 5) IFIT
   44 JGO = 2
      READ 20, ITERMS
      IF (ITERMS .LE. 0) GO TO 9997
      DO 46 I = 1, ITERMS
      DO 45 J = 1, ITERMS
   45 A(I,J) = AK(I,J)
   46 B(I,1) = BK(I,1)
      GO TO 411
    5 DO 51 I = 1, ITERMS
      BK(I,1) = 0.0
      DO 51 J = 1, ITERMS
   51 A(I,J) = 0.0
      C = 0.
      LBACK = 2
      JBACK = 1
      JGO = 2
      L = 1
      GO TO 301
    5 FKC = 0.0
      DO 601 I = 1, ITERMS
  601 FKC = FKC + B(I,1)*Y(I)
      FKR = FKC*X(L)
      FNC = 1. + FKR*(2. + FKR)/3.
      XC = X(L)*COS(PA(L))
      SIN2 = G*FNC*XC*.0001/VS
      IF (SIN2 .GT. .999999999) SIN2 = .999999999
      THEOC(L) = ATAN(SIN2/SQRT(1. - SIN2*SIN2))*.5
      IF (THEO(L) .GT. PI4) THEOC(L) = PI2 - THEOC(L)
  605 Z = XC/(VOS(L)*COS(THEO (L) + PA(L)))
      TC(L) = SQRT((60000.*Z*VOS(L)*SIN(THEO (L)+PA(L))-60000.*
     1         SIN(PA(L))*X(L) - G*Z*Z)/G*.5)
      DELT = TF(L)*100. - TC(L)
C
C   **** DEFINE TERMS FOR DELT FIT AND EVALUATION                      ****
C
   61 Y(K 1) = 1.
      Y(K 2) = X(L)
      Y(K 3) = VGS(L)
```

```
      Y(K 4) = DENSE(L)
      Y(K 5) = TKS(L)
      Y(K 6) = HXS(L)
      Y(K 7) = PA(L)
      Y(K 8) = X(L)*VOS(L)
      Y(K 9) = X(L)*DENSE(L)
      Y(K10) = X(L)*TKS(L)
      Y(K11) = X(L)*HXS(L)
      Y(K12) = X(L)*PA(L)
      Y(K13) = VOS(L)*DENSE(L)
      Y(K14) = VOS(L)*TKS(L)
      Y(K15) = VOS(L)*HXS(L)
      Y(K16) = VOS(L)*PA(L)
      Y(K17) = DENSE(L)*TKS(L)
      Y(K18) = DENSE(L)*HXS(L)
      Y(K19) = DENSE(L)*PA(L)
      Y(K20) = TKS(L)*HXS(L)
      Y(K21) = TKS(L)*PA(L)
      Y(K22) = HXS(L)*PA(L)
      Y(K23) = XS
      Y(K24) = PS
      Y(K25) = X(L)*DS
      Y(K26) = X(L)*HS
      Y(K27) = X(L)*PS
      Y(K28) = VOS(L)*XS
      Y(K29) = VOS(L)*DS
      Y(K30) = VOS(L)*HS
      Y(K31) = VOS(L)*PS
      Y(K32) = DENSE(L)*XS
      Y(K33) = DENSE(L)*HS
      Y(K34) = DENSE(L)*PS
      Y(K35) = PA(L)*XS
      Y(K36) = PA(L)*VS
      Y(K37) = PA(L)*DS
      Y(K38) = PA(L)*TS
      Y(K39) = PA(L)*HS
      Y(K40) = X(L)*XS
      Y(K41) = PA(L)*PS
      Y(K42) = XV*DENSE(L)
      Y(K43) = XV*HXS(L)
      Y(K44) = XV*PA(L)
      Y(K45) = XD*HXS(L)
      Y(K46) = XD*PA(L)
      Y(K47) = X(L)*HXS(L)*PA(L)
      Y(K48) = VD*HXS(L)
      Y(K49) = VD*PA(L)
      Y(K50) = DENSE(L)*TKS(L)*HXS(L)
      Y(K51) = DENSE(L)*HXS(L)*PA(L)
      GO TO (65, 75) JBACK
   63 DO 67 I = 1, KTERMS
      DO 66 J = 1, KTERMS
   65 A(I, J) = A(I,J) + Y(I)*Y(J)
   67 BK(I,1) = BK(I,1)+ Y(I)*DELT
      C = C + DELT*DELT
      L = L + 1
```

```
      IF (L - NPOINT) 301, 301, 68
   68 DO 702 I = 1, KTERMS
      DO 701 J = 1,KTERMS
  701 AL(I,J) = A(I,J)
  702 BL(I,1) = BK(I,1)
C
C   **** INVERT NORMAL MATRIX FOR DELT FUNCTION                         ****
C
  705 CALL MATNVR(A, KTERMS, BK,1, DETERM, IERR)
      IF (IERR) 9999, 71, 9999
   71 JBACK = 2
      SS = 0
      DO 72 I = 1,KTERMS
   72 SS = SS - BK(I,1)*BL(I,1)
      RMS = SQRT(SS/COUNT)
      PRINT 420, RMS
      PRINT 430,KTERMS,K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,
     1          K15,K16,K17,K18,K19,K20,K21,K22,K23,K24,K25,K26,K27,K28,
     2          K29,K30,K31,K32,K33,K34,K35,K36,K37,K38,K39,K40,K41,K42,
     3          K43,K44,K45,K46,K47,K48,K49,K50,K51
      PRINT 210, (BK(I,1), I = 1, KTERMS)
      GO TO (74, 74, 74, 73) IFIT
   73 READ 20, KTERMS
      IF (KTERMS .EQ. 0) GO TO 9997
      DO 736 I = 1, KTERMS
      DO 735 J = 1, KTERMS
  735 A(I,J) = AL(I,J)
  736 BK(I,1)= BL(I,1)
      GO TO 705
   74 IF (IPRINT) 742, 741, 742
  741 PRINT 200,IDEN(IW),IDEN(IX),IDEN(IY),IDEN(IZ), ITYP(ITYPE)
      PRINT 710
  742 DO 8 L = 1, NPOINT
  801 XS = X(L)*X(L)
      PS = PA(L)*PA(L)
      HS = WXS(L)*WXS(L)
      TS = TKS(L)*TKS(L)
      DS = DENSE(L)*DENSE(L)
      VS = VOS(L)*VOS(L)
      XD = X(L)*DENSE(L)
      XV = X(L)*VOS(L)
      VD = VOS(L)*DENSE(L)
      GO TO 61
   75 DO 76 I=1, KTERMS
   76 TC(L) = TC(L) + Y(I)*BK(I,1)
      T2 = TF(L)*100.
      X1 = X(L)*3333.333333
C
C   **** COMPUTE ERRORS FOR EACH DATA POINT AND PRINT RESULTS           ****
C
      T2ERR = TC(L)-T2
      EGERR =(THEOC(L) - THEO(L))*3437.7468
      R2ERR = EGERR*100./DX(L)
      R2ERRM = (R2ERR*1000.)/X1
      WJ = R2ERR*TAN(AF(L))
```

```
      IF (IPRINT) 89, 81, 89
   81 TK = TKS(L)*100.
      HX = HXS(L)*100.
      DENS= DENSE(L)*100.
      THE = THEO(L)*57.29578
      PA1 = PA(L)*57.29578
      V0 = VOS(L)*10000.
      MT1 = MT(L)*100.
      PRINT 80, L,THE,V0,DENS,TK,HX,PA1,X1,T2,EGERR,T2ERR,R2ERR,R2ERRM,
     1          MD
C
C    **** ACCUMULATE ERRORS FOR OVERALL EVALUATION                    ****
C
   89 ACUME(1) = ACUME(1) + R2ERR
      ACUME(2) = ACUME(2) + R2ERRM
      ACUME(3) = ACUME(3) + T2ERR
      ACUME(4) = ACUME(4) + EGERR
      ACUME(5) = ACUME(5) + MD
      ACUME(6) = ACUME(6) + ABS(R2ERR)
      ACUME(7) = ACUME(7) + ABS(R2ERRM)
      ACUME(8) = ACUME(8) + ABS(T2ERR)
      ACUME(9) = ACUME(9) + ABS(EGERR)
      ACUME(10) = ACUME(10) + ABS(MD)
      ACUME(11) = ACUME(11) + R2ERR*R2ERR
      ACUME(12)= ACUME(12)+ R2ERRM*R2ERRM
      ACUME(13)= ACUME(13)+ T2ERR*T2ERR
      ACUME(14)= ACUME(14)+ EGERR*EGERR
      ACUME(15) = ACUME(15) + MD*MD
      GO TO (8, 8, 3) IFIT
    8 CONTINUE
      GO TO 9
  895 PRINT 200,IDEN(IW),IDEN(IX),IDEN(IY),IDEN(IZ), ITYP(ITYPE)
      PRINT 410
      PRINT 430,      ITERMS,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,
     2          I14,I15,I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27
     3         ,I28,I29,I30,I31,I32,I33,I34,I35,I36,I37,I38,I39,I40,I41
     4         ,I42,I43,I44,I45,I46,I47,I48,I49,I50,I51
      PRINT 210, (B(I,1), I = 1, ITERMS)
      PRINT 430,KTERMS,K1,K2,K3,K4,K5,K6,K7,K8,K9,K10,K11,K12,K13,K14,
     1         K15,K16,K17,K18,K19,K20,K21,K22,K23,K24,K25,K26,K27,K28,
     2         K29,K30,K31,K32,K33,K34,K35,K36,K37,K38,K39,K40,K41,K42,
     3         K43,K44,K45,K46,K47,K48,K49,K50,K51
      PRINT 210, (BK(I,1), I = 1, KTERMS)
C
C    **** COMPUTE STATISTICAL QUANTITIES AND PRINT OUT QUANTITIES    ****
C
    9 DO 91 I = 1, 10
   91 RESULT(I) = ACUME(I)/COUNT
      DO 92 I = 11, 15
   92 RESULT(I) = SQRT(ACUME(I)/COUNT)
      PRINT 70
      PRINT 200,IDEN(IW),IDEN(IX),IDEN(IY),IDEN(IZ), ITYP(ITYPE)
      PRINT 70
      PRINT 50, RESULT(1),RESULT(6),RESULT(11),RESULT(2),RESULT(7),
     1          RESULT(12),RESULT(3),RESULT(8),RESULT(13),RESULT(4),
```

```
      2          RESULT(9),RESULT(14),RESULT(5),RESULT(10),RESULT(15)
 9997 GO TO 1
 9999 PRINT 900, IERR
      STOP
   10 FORMAT (14I5)
   20 FORMAT (16I5)
   30 FORMAT (F7.5, 14X, F7.4,F8.5,F7.4,F7.5,3F6.3,F7.4,F5.3)
   50 FORMAT (1HK,54X,39HAVERAGE        MEAN ABSOLUTE        RMS/
     1          55X,40H ERROR              ERROR             ERROR//
     2             27X,17HRANGE ERROR (YDS), 3(F17.1)//
     3             27X,17HRANGE ERROR (MIL), 3(F17.1)//
     4             27X,17HTF    ERROR (SEC), 3(F17.3)//
     5             27X,17HANGLE ERROR (MIN), 3(F17.3)//
     6             27X,19HMISS DISTANCE (YDS), F15.1, 2(F17.1))
   60 FORMAT (1H1)
   70 FORMAT (1HL)
   80 FORMAT(1X,I4,F7.2,F10.0,F10.1,F9.1,F7.1,6X,F9.2,F11.1,F7.2,
     1        F16.2,F8.2,F8.1,F8.1,F9.1)
  100 FORMAT (1H1,52X,27HTIME OF FLIGHT COEFFICIENTS//
     1         27X, 6E13.7/ 27X, 6E13.7)
  200 FORMAT (1H1, 37X, 39HEVALUATION OF NAVAL WEAPONS LABORATORY ,
     1         17HFUNCTIONALIZATION,// ,50X,4A8//62X,A8)
  210 FORMAT (62X,5E14.7)
  220 FORMAT (5E14.7)
  410 FORMAT (1H0, 4H RMS,6X,6HNUMBER,19X,10HTERMS USED,44X,
     1         12HCOEFFICIENTS/11X,8HOF TERMS,72X,10HFKC / DELT)
  420 FORMAT (1H0, F10.7)
  430 FORMAT (14X,I2,3X,14(1X,I2)/19X,14(1X,I2)/19X,14(1X,I2)/
     1         19X,14(1X,I2))
  710 FORMAT (1H0,4X,45HELEVATION  INITIAL   DENSITY    TEMP  RANGE  ,
     1        32HMOTOR  POSITION   SLANT  TIME OF, 9X,11HANGLE    TF,5X,
     2        21HRANGE     RANGE   MISS/7X,25HANGLE     VELOCITY  (P/C OF,
     3        4X,44H(DEG  WIND   TEMP      ANGLE     RANGE  FLIGHT,10X,
     4        41HERROR     ERROR  ERROR     ERROR   DISTANCE/
     5        7X,52H(DEG)     (FT/SEC)  STANDARD)     F)  (KTS)  (DEG)
     6        21H(DEG)     (YDS)  (SEC),11X,25H(MIN)     (SEC)  (YDS)
     7        13H(MILS)   (YDS)/)
  900 FORMAT(30H MATRIX WILL NOT INVERT-IERR =, I5)
 3310 FORMAT (19H CHECK DEGOX TABLES)
      END
```

```
      SUBROUTINE MATNVR(A,NNN,B,M,DETERM,IERR)
      DIMENSION A(25, 25), B(25, 1)
      DIMENSION INDEX(76,2), IPIVOT(76)                            GAUSS160
C                                                                  GAUSS130
      EQUIVALENCE (IROW,JROW), (ICOLUM,JCOLUM), (AMAX, T, SWAP)    GAUSS140
C                                                                  GAUSS150
C     INITIALIZATION                                               GAUSS160
C
      N = NNN                                                      GAUSS190
   10 DETERM=1.0                                                   GAUSS200
   15 DO 20 J=1,N                                                  GAUSS210
   20 IPIVOT(J)=0                                                  GAUSS220
   30 DO 550 I=1,N                                                 GAUSS240
C                                                                  GAUSS250
C     SEARCH FOR PIVOT ELEMENT                                     GAUSS260
C                                                                  GAUSS270
   40 AMAX=0.0                                                     GAUSS280
   45 DO 105 J=1,N                                                 GAUSS290
   50 IF (IPIVOT(J)-1) 60, 105, 60                                 GAUSS300
   60 DO 100 K=1,N                                                 GAUSS310
70    IF (IPIVOT(K)-1) 80,100,899                                  GAUSS320
   80 IF (ABS(AMAX)-ABS(A(J,K))) 85, 100, 100                      GAUSS330
   85 IROW=J                                                       GAUSS340
   90 ICOLUM=K                                                     GAUSS350
   95 AMAX=A(J,K)                                                  GAUSS370
  100 CONTINUE                                                     GAUSS380
  105 CONTINUE                                                     GAUSS420
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1                              GAUSS430
      IF (A(ICOLUM,ICOLUM))130,899,130                             GAUSS440
C                                                                  GAUSS450
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL            GAUSS460
C                                                                  GAUSS470
  130 IF (IROW-ICOLUM) 140, 260, 140                               GAUSS480
  140 DETERM=-DETERM                                               GAUSS490
  150 DO 200 L=1,N                                                 GAUSS500
  160 SWAP=A(IROW,L)                                               GAUSS510
  170 A(IROW,L)=A(ICOLUM,L)                                        GAUSS520
  200 A(ICOLUM,L)=SWAP                                             GAUSS530
  210 DO 250 L=1, M                                                GAUSS540
  220 SWAP=B(IROW,L)                                               GAUSS550
  230 B(IROW,L)=B(ICOLUM,L)                                        GAUSS560
  250 B(ICOLUM,L)=SWAP                                             GAUSS570
  260 INDEX(I,1)=IROW                                              GAUSS580
  270 INDEX(I,2)=ICOLUM                                            GAUSS590
  310 PIVOT   =A(ICOLUM,ICOLUM)                                    GAUSS600
  320 DETERM=DETERM*PIVOT                                          GAUSS610
C                                                                  GAUSS620
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT                            GAUSS630
C                                                                  GAUSS640
  330 A(ICOLUM,ICOLUM)=1.0                                         GAUSS650
  340 DO 350 L=1,N                                                 GAUSS660
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT                                GAUSS670
  360 DO 370 L=1,M                                                 GAUSS680
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT                                GAUSS690
C
```

```
C      REDUCE NON-PIVOT ROWS                                           GAUSS700
C                                                                      GAUSS710
  380 DO 550 L1=1,N                                                    GAUSS720
  390 IF(L1-ICOLUM) 400, 550, 400                                      GAUSS730
  400 T=A(L1,ICOLUM)                                                   GAUSS740
  420 A(L1,ICOLUM)=0.0                                                 GAUSS750
  430 DO 450 L=1,N                                                     GAUSS760
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T                                    GAUSS770
  460 DO 500 L=1,M                                                     GAUSS780
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T                                    GAUSS790
  550 CONTINUE                                                         GAUSS800
C                                                                      GAUSS810
C      INTERCHANGE COLUMNS                                             GAUSS820
C                                                                      GAUSS830
  600 DO 710 I=1,N                                                     GAUSS840
  610 L=N+1-I                                                          GAUSS850
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630                         GAUSS860
  630 JROW=INDEX(L,1)                                                  GAUSS870
  640 JCOLUM=INDEX(L,2)                                                GAUSS880
  650 DO 705 K=1,N                                                     GAUSS890
  660 SWAP=A(K,JROW)                                                   GAUSS900
  670 A(K,JROW)=A(K,JCOLUM)                                            GAUSS910
  700 A(K,JCOLUM)=SWAP                                                 GAUSS920
  705 CONTINUE                                                         GAUSS930
  710 CONTINUE                                                         GAUSS940
      IERR = 0
  740 RETURN                                                           GAUSS950
  899 IERR = 1
      RETURN                                                           GAUSS970
      END                                                              GAUSS980
```

APPENDIX H

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13. ABSTRACT

The Effective Drag Functions derived by the Naval Weapons Laboratory for the computation of gun ballistic data in digital gunfire control systems are presented. The accuracy and derivation of the functions are given as well as the least-squares coefficients computed for 3- and 5-inch projectiles. FORTRAN listings of the three programs used in the computation of the coefficients are given in the appendices.

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